SENSITIVITY ANALYSIS OF BRAWLER PILOT SKILL LEVELS

THESIS

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Dedication

I dedicate this work to my mother and father. They have instilled in me the value of an education and empowered me with the confidence to achieve my dreams.

Acknowledgments

I am deeply indebted to a host of people who made this thesis possible. I have been especially fortunate to have so many wonderful professors, friends, and co-workers. To each of them, I extend my heartfelt gratitude:

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And last, but not least I am grateful to Kathy, my wife, shepherd, and forever friend, for her continuing support, faith, and love through all the ups and downs. You love unconditionally and motivate me to achieve the impossible. No one has had more positive influence on me in my life.

I would be remiss if I did not mention my son, Dexter, the greatest single joy of my life whose anticipated and welcomed distractions focused my priorities in life. I love you.

Daniel C. Buschor

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List of Symbols

English Symbols

Symbol	Definition
$\mathbf{0}$	Vector of Zeros
$\mathbf{1}$	Vector of Ones
$\mathbf{b}$	Vector of Estimated Regressor Coefficients
$\mathbf{e}$	Vector of Residuals
$\mathbf{D}$	Box-Behnken Design Matrix
F	F Statistical Distribution
$\mathbf{I}$	Identity Matrix
i	Integer Subscript
j	Integer Subscript
K	Thousands of Feet
k	Integer Number of Factors
N	Integer Number
n	Integer Number of Responses
$N(\mathbf{0}, \mathbf{I}\sigma^2)$	Normal Distribution, mean 0, variance σ^2
Nm	Nautical Miles
R^2	Coefficient of Multiple Determination
S	Half Range
x	Regressor Variables
$\mathbf{X}$	Design Matrix of Regressor Variables
y	Response Variable

$\mathbf{y}$	Vector of Responses
$\hat{\mathbf{y}}$	Vector of Fitted Responses

Greek Symbols

Symbol	Definition
α	Alpha – Statistical Significance Level
β	Beta – Regressor Coefficient
ε	Epsilon – Random Error
ξ	Xi – Uncoded Value
σ^2	Sigma Squared – Variance

Abbreviations

Abbreviation	Definition
AFIT	Air Force Institute of Technology
AFSAA	Air Force Studies & Analyses Agency
ANOVA	Analysis of Variance
BBD	Box-Behnken Design
BVR	Beyond Visual Range
DOD	Department of Defense
DSA	Decision-Science Applications, Inc.
GCI	Ground Control Intercept
GUI	Graphical User Interface
LOF	Lack of Fit
MOE	Measure of Effectiveness

MSE	Mean Square Error
MSLF	Mean Square Lack of Fit Error
MSPE	Mean Square Pure Error
MSR	Mean Square Regression
ORI	Operational Readiness Inspection
RSM	Response Surface Methodology
SURVIAC	Survivability/Vulnerability Information Analysis Center
US	United States
USAF	United States Air Force
WVR	Within Visual Range

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Abstract

BRAWLER is a high resolution air-to-air combat simulation model used for engagement-level analyses of few-on-few air combat. It uses a value driven decision logic to help simulate pilot behavior. In order to account for varied pilot skill levels, BRAWLER has defined three skill levels; *Rookie*, *Pilot*, and *Ace*. A *Rookie* can track up to three aircraft in its mental model, the *Pilot*, up to five aircraft, while an *Ace* has no limit. Further, each skill level varies the amount of time before a known aircraft, which has not been recently observed, is purged from the pilot's mental model (i.e., memory time). Past analyses using BRAWLER have exclusively used *Ace* pilots. This thesis focuses on the effects due to pilot skill level in air-to-air combat by using different combinations of *Rookie*, *Pilot*, and *Ace* skill levels in the BRAWLER air-to-air engagement model.

SENSITIVITY ANALYSIS OF BRAWLER PILOT SKILL LEVELS

Chapter 1 - Introduction

Operational readiness is a cornerstone of the United States (US) military defense posture. Operational readiness implies a level or ability to respond militarily producing favorable outcomes. The Department of Defense (DOD) and military leaders routinely try to measure or assess military operational readiness. Training is one surrogate measure of operational readiness. Reduced levels of combat-specific training often imply reduced levels of operational readiness. Any reduction in operational readiness, whether real or perceived, means reduced military capability, something that concerns US military leadership.

The United States Air Force (USAF) is in a period of tremendous change. The lack of a superpower threat has prompted dramatic force cuts yet "hot spots" and commitments throughout the world have kept the USAF operational tempo (ops tempo) extremely high. Despite the increased flying hours associated with this higher ops tempo, overall fighter operational readiness has declined due to reduced combat-specific training. These concerns have prompted inquiries regarding how to quantify the effects of reduced fighter pilot operational readiness. The USAF's primary air-to-air analysis tool is Air Force Studies and Analyses Agency's (AFSAA) BRAWLER constructive simulation model. Because of its wide acceptance and inclusion in the Air Force Analysis Toolkit [6], BRAWLER is the prime candidate tool to try and quantify the operational impact of reduced fighter operational readiness.

BRAWLER is an air-to-air combat simulation model used for engagement-level analyses of few-on-few air combat. BRAWLER is considered a "high resolution" model due to its engineer-

ing level models of hardware (aircraft, radar, etc.) and physical effect (drag, lift, etc.). BRAWLER employs a value driven decision logic to help model pilot behavior. Limited pilot capabilities are modeled in BRAWLER through pilot skill level, inherent bias, and induced goal fixation. This thesis effort investigates one—pilot skill level. BRAWLER accounts for varied pilot skill levels by defining three discrete skill levels—*Rookie*, *Pilot*, and *Ace*. These skill levels differ primarily in the mental capacity provided the pilot. A *Rookie* tracks up to three aircraft in their mental model, a *Pilot* up to five aircraft, while an *Ace* has no limit on the number of aircraft tracked. Furthermore, each skill level varies memory time–the amount of time before a known aircraft, which has not been recently observed, is purged from the pilot's mental model. Past analyses using BRAWLER exclusively used *Ace* pilots. One rational for this common assumption is that the *Ace* skill level mirrors USAF goals of maintaining a fully operational ready force. Few, if any, studies use BRAWLER to study the effects of reduced pilot proficiency.

This thesis specifically examines the BRAWLER mental model to assess BRAWLER's capability to reasonably quantify the impact of reduced pilot readiness in air-to-air combat. Specifically, this thesis experimentally investigates the influence of varied pilot skill levels on typical BRAWLER measures of effectiveness (MOEs)—friendly survivability, friendly lethality, and overall air-to-air exchange ratio.

The specific goals of this research are: (1) determine what impact different combinations of *Rookie*, *Pilot*, and *Ace* skill levels have on standard BRAWLER output MOEs and (2) to investigate any unique underlying factors that surface when varying pilot skill level in BRAWLER.

Chapter 2 is the heart of this thesis, and resembles a final journal-ready article. Chapter 3 provides a summary of this thesis, a discussion of pertinent results, and directions for further research. Particular details supporting this thesis are contained in the appendices. Appendix A contains the experimental design matrix used to investigate the combinations of pilot skill levels. Appendix B

contains the BRAWLER scenario file (**SCNRIO**) defining the 4 v 4 air combat scenario used as the basis for this research. *Lprnts* are diagnostic print statements within the BRAWLER simulation used to obtain simulation output for subsequent post-processing and analysis. Appendix C contains an *lprnt* cross reference matrix corresponding to BRAWLER routines that affect the pilot's mental model. Finally, Appendix D contains the AWK programming script used to post-process the BRAWLER simulation output into meaningful information.

Chapter 2 - Varying Pilot Skill Levels in BRAWLER

2.1 Introduction

In February of 1991 Operation Desert Storm ended as the coalition force commander, General Schwarztkopf, accepted the surrender of Saddam Hussein. Shortly thereafter, Operation Southern Watch was initiated to prevent persecution of Iraqi Kurds. Through early 1998, this mission remains active to deter further Iraqi aggressions. In November of 1995, the Dayton Peace Accords brought a form of "peace" to war-torn Bosnia. Called by various names, the USAF continues to maintain a significant flying presence over Bosnia helping to maintain the fragile peace of the area. These are but two examples of operational demands placed on the USAF during an extended period of "peace".

Continuing overseas commitments coupled with the USAF subsequently entering a period of massive downsizing, means increased deployments (rotations) of air-to-air combat fighter units to maintain various "no fly" zones. Despite ample flying hours, poor and limited in-theater combat-related training and increases in the length and frequency of the rotations have reduced overall operational readiness prompting senior military leadership to question, "Is our fighter force capable of doing the job if called upon?" Accurate modeling and simulation analysis may provide insight into this question.

Air Force Studies and Analyses Agency (AFSAA) uses BRAWLER to examine questions pertaining to air-to-air combat. BRAWLER is a high resolution air-to-air combat simulation model used for engagement-level analyses of few-on-few air combat. As such, BRAWLER's primary purpose is for studying the effectiveness of new or existing weapons or avionics systems, and any supporting tactical doctrines, in the air-to-air combat environment.

BRAWLER differs from other air-to-air models in its pilot modeling. Unlike competitor models that treat pilot behavior in a purely rule-based fashion, BRAWLER employs a value-based decision logic to help guide the BRAWLER pilot decision process. Based on an individualized assessment of the combat situation, supplemented with rules (or tactics) based on doctrine, the BRAWLER pilot "decides" his next set of actions.

BRAWLER models limited pilot capabilities through pilot skill level, inherent bias, and induced goal fixation. Built into the BRAWLER model is a means to vary pilot skill level, the focus of this research. Three discrete levels are defined—*Rookie*, *Pilot*, and *Ace*. These levels differ primarily in terms of mental capacity, or situational assessment, of the combat situation. Though well established in BRAWLER, these skill level distinctions have not been thoroughly examined. In fact, past analyses using BRAWLER have exclusively used fully mission capable, or *Ace* skill level pilots. This leads one to question whether or not varying pilot skill level in BRAWLER truly represents degraded mission readiness in a fighter pilot force. In other words, can one use BRAWLER to examine the effects of limited pilot capabilities on combat situational assessment and decision making.

This thesis investigates the ability of BRAWLER to model the effects that various combinations of pilot skill levels have on air-to-air engagement outcomes. Specifically, what impact does various combinations of *Rookie*, *Pilot*, and *Ace* skill levels produce on the standard BRAWLER output Measures of Effectiveness (MOEs)—Exchange Ratio, Lethality, and Survivability. With these empirical results, and an analytical assessment of the BRAWLER mental model, this thesis assesses BRAWLER's potential to help quantify fighter operational readiness.

2.2 BRAWLER Air Combat Simulation

BRAWLER is a discrete-event simulation designed to simulate air-to-air combat between multiple flights of aircraft in both the within-visual-range (WVR) and beyond-visual-range (BVR) environment. BRAWLER incorporates data-driven engineering sub-models of the hardware relative to the air-to-air environment, with new or improved hardware models incorporated as needed. The detailed modeling of combat pilots' decision making distinguishes BRAWLER from other models of air combat. Additionally, BRAWLER emphasizes modeling cooperative tactics and individual situational awareness, both of which are crucial in an actual air combat environment.

One of the key factors in modeling air combat is an accurate representation of the pilot decision-making process as this drives the outcome of air-to-air engagements. BRAWLER pilots are modeled as complete decision entities that explicitly perform the functions of data input, mental model update, and decision-making [1, 2.3.1-1]. In the past, flight-versus-flight engagement outcomes involved extrapolating one-versus-one engagements, which limited the usefulness of the results. Human decisions in flight-versus-flight engagements are extremely complex. For example, "surprise" is directly responsible for a majority of air-to-air kills and executing closely coordinated maneuvers between flight members is a function of how well they inter-communicate. Further, the spatial relationships between many aircraft are much more complicated than the relationship between two aircraft. This makes a pilot's situational awareness task much tougher. Thus, an accurate model of flight-versus-flight air combat must correctly portray the information available to the pilot and base simulated pilot decisions solely on this information [7, 60]. This complexity causes decision tree or rule-based methods, such as might be used in one-versus-one engagements, to be of little practical value in a flight-versus-flight environment. As a result, Decision-Science Applications, Inc. (DSA), developers of BRAWLER, adopted a dual approach to the modeling of the pilot decision making process: "value-driven decision-making" and "information-oriented decision architecture." This

dual approach provides a practical solution to the problems involved in modeling multiple aircraft in air combat. As a result, BRAWLER is the first computer model of air combat considered "realistic" of pilot behavior by USAF pilots since it accurately models pilot situation perception and its consequences [1, 2.1.1-1].

The information-oriented decision architecture feature models the flow of information into each pilot's personal situation perception (their own mental model). All pilot decisions are based on this personal perception. This facilitates the modeling of surprise, confusion and the limited ability of pilots to communicate and cooperate. Figure 1 is a conceptual representation of information flow

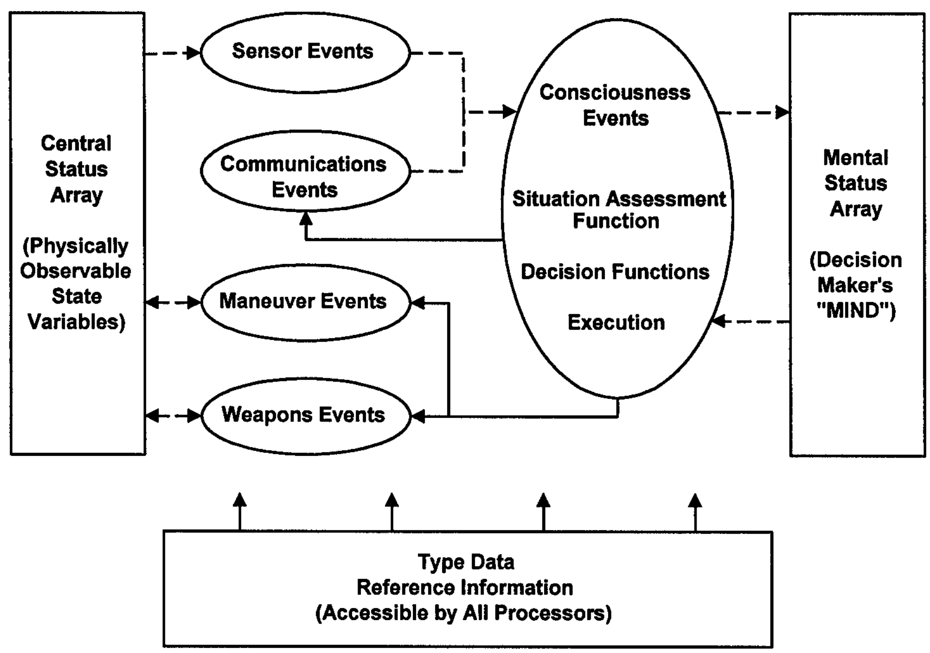

Figure 1. Conceptual Representation of Information Flow

within BRAWLER. The central status arrays contain the true physical state of simulation, in other words, ground truth for the simulation. This includes information describing aircraft and missile positions, velocities, and orientations, as well as less directly observable items such as fuel state.

Each BRAWLER pilot has a personal mental status array (his or her mental model) which mirrors the central status in structure, but not in content. Thus, the pilot has imperfect information of other aircraft, what those aircraft are doing, and whether there are missiles in the air. In short, the pilot may be "surprised" due to what is unknown [2, 2.1-3].

Consciousness events are the major pilot events in BRAWLER [5]. All pilot actions are simulated during a consciousness event. Note in Figure 1, conscious events, which are responsible for pilot decisions, do not involve the central status. All decisions are made on the basis of the data contained in the pilot's mental model. Three sequential phases—situation assessment, decision, and execution occur within each consciousness event. During the situation assessment phase the pilot incorporates any new sensory data into their mental model. Information arrives in the mental model via sensor events such as visually searching for other aircraft and missiles, viewing radar and other sensing devices, or through communication with other flight members. Incoming information is processed by the pilot and deposited in his mental status array. This processing updates values assigned to physical variables, like speed and altitude, resulting in new assessments of the current tactical situation. The decision phase of the consciousness event uses the updated mental model to make decisions according to a hierarchy of topics as illustrated in Figure 2. Once a decision has been made, the execution phase results in physical actions, either directly via communications, aircraft maneuver events, and weapons employment events or indirectly by setting objectives for other decisions. It is these physical actions that alter the central status array [1, 2.1.1-2].

The BRAWLER decision hierarchy results in a layered decision making process. The effect of high-level decisions is to control the low-level decisions by modifying their evaluation functions and determining which alternatives are considered. There is reason to believe that this layered decision-making process parallels the real human decision process [1, 2.1.1-4]. At the highest level, the flight posture decision determines the general course of action. It is made on the basis of a

broad description of the situation and on various combat priorities. At the next level, the flight lead determines the tactics used to set the flight posture. This is conveyed to the other flight members via a communications event, which influences the alternative actions they consider. For instance,

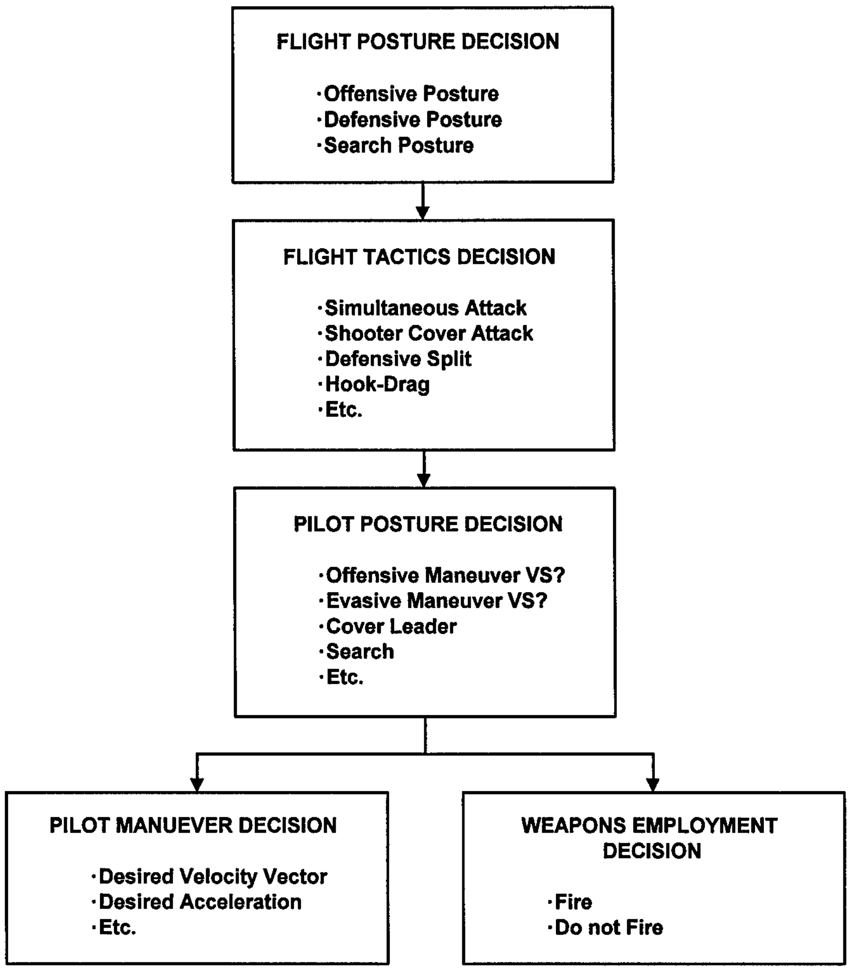

Figure 2. BRAWLER Decision Hierarchy

and "order" to a wingman to attack a certain hostile aircraft results in that wingman perceiving that hostile as a greater threat. This adds realism since a wingman's perception of the situation may differ from that of his leader. Since an "order" serves to influence, not force, an action upon a wingman, the wingman will exhibit a certain common sense in his actions. He will, for example, try

to evade any hostile he perceives as extremely threatening, despite and "order" to attack a different hostile. In the next level, pilot posture decision, pilots decide upon a general course of action for their aircraft. A pilot determines which hostiles are "important" for both offensive and defensive purposes. For instance, who is he attacking, who is he evading, or is he just providing support for his leader? The maneuver decision and weapons employment decision occur at the lowest level. During a maneuver decision, a pilot considers things like "get on a hostile's tail," "avoid the ground," or "force a pursuer to overshoot." In a weapons employment decision, the pilot is trying to decide whether to shoot based on considerations such as whether the hostile is in the weapon's envelope, whether the shot can be improved by waiting, or whether their is a risk associated with continuing to press the attack [1, 2.1.1-7].

Decisions in BRAWLER employ the value-driven decision-making technique. A value-driven decision explicitly considers decision alternatives and assigns a score to each of them. Thus, a BRAWLER pilot rank orders his decision alternatives. Figure 3 shows the value-driven human decision processes in BRAWLER. The upper loop represents the model-building process (model-building in the sense of assigning values to the variables that describe the situation) and is executed once each pilot consciousness event. The lower loop is executed each time a decision is made and is repeated for each alternative being considered. Each alternative is projected into an immediate future state and alternative scoring is based on this predicted state. That is, the mental model predicts what the situation might be if the alternative is implemented. An evaluation model (value function) places a numerical score on the resulting situation. The alternative scoring the highest is selected for implementation.

Figure 4 illustrates an example of the BRAWLER decision logic. Here Viper 1 is presented with two alternatives. He can engage Mig 1 or he can maneuver to support his wingman, Viper 2, and engage Mig 2, which is threatening Viper 2. Alternative 1 illustrates that the value of killing

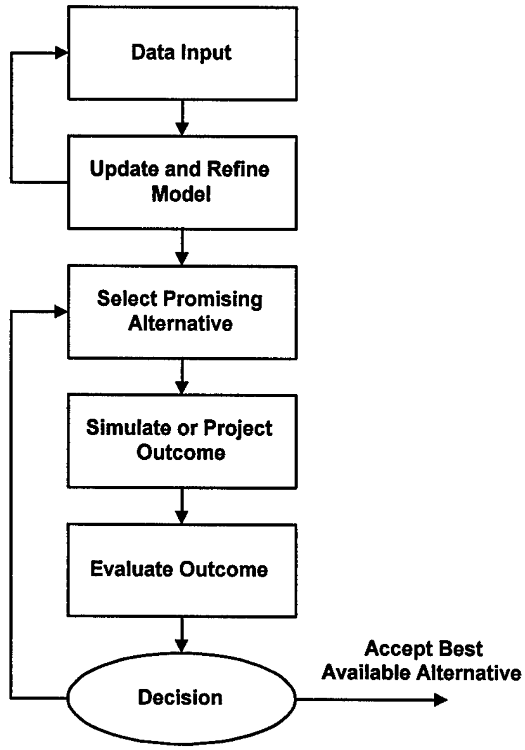

Figure 3. The Human Decision Process

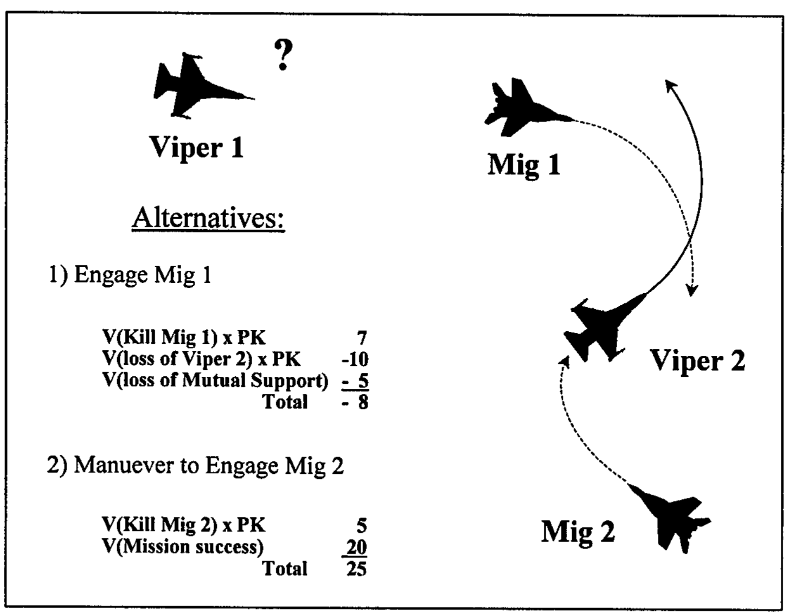

Figure 4. Decision Logic Example

Mig 1 minus the value of loosing Viper 2 minus the value of losing mutual support results in a score of -8. Alternative 2 shows the value of killing Mig 2 plus the value of mission success results in a score of $+25$. Thus, in this example, maneuvering to engage Mig 2 in mutual support of Viper 2 results in a higher score and is the best alternative. Naturally, a certain level of continuity in decisions is maintained among consciousness events.

BRAWLER pilots are complete decision entities explicitly performing the functions of data input, mental model update, and decision-making [1, 2.3.1-1]. Mental model updating is one of the most important functions and is where varied pilot skill levels effect the BRAWLER pilot. This updating falls into two categories—physical parameters and situational awareness. Updating physical parameters means changing values of state variables. For example, changing the range estimate of a hostile aircraft or the airspeed of a friendly aircraft. On the other hand, updating situational awareness involves perception. For example, given some change in range, a hostile may no longer be perceived as a threat and may be dropped from the mental status array of that pilot.

A fundamental assumption of BRAWLER is that a pilot's situational awareness is a function of pilot proficiency. A more proficient pilot can assess and assimilate more information concerning aircraft in a scenario. There are three discrete proficiency levels: *Rookie*, *Pilot*, and *Ace*. The maximum number of aircraft allowed in the *Ace* mental model (BRAWLER variables *maxac_hi* or *macmnd*) is currently set to the number of aircraft in the simulation (*mac*), meaning an *Ace* has unlimited mental capacity. For the *Pilot* and *Rookie* skill levels the maximum number of aircraft allowed in their mental models (BRAWLER variables *maxac_med, maxac_low*) are 5 and 3, respectively. A prioritizing algorithm "scores" all aircraft to determine which aircraft are placed in the pilot's mental model. The algorithm first places the highest scoring friendly and highest scoring observed hostile in a pilot's mental model, with remaining "slots" filled with a mix of the highest scoring friendly and hostiles.

Currently, *Ace* pilots appear to operate with an unrealistically high (unlimited) situational awareness capability. Sinclair [13, 2] asserts that users employing BRAWLER pilots at maximum theoretical capability (i.e., *Ace* skill level), assume skill level will not significantly affect the outcome of most scenarios. Sinclair states, "It's difficult to make an argument that pilot limitations have no effect on combat outcomes without at least testing the assumption" [13, 2]. To test his assumption, Sinclair used BRAWLER to examine pilot combat performance under opposing threat deception tactics—in reality, a very stressing combat situation.

Based on studies of combat aviators, Shaw [12] suggests that during task overloading, pilots will attempt to complete all tasks in a degraded manner. As the overload situation persists, a pilot will discard lower priority tasks, eventually focusing on a single task—target fixation. Shaw concludes that pilots under stressing situations can perform two simultaneous "difficult" tasks [12].

Sinclair counters Shaw's conclusion citing psychological results indicating that humans can perform between 5 and 9 simple dissimilar tasks simultaneously. Thus, considering human capability as falling somewhere between 2 and 9 complex tasks, Sinclair studies values of 3, 5, 7, and unlimited tasks. He defines a task as tracking an individual aircraft.

Sinclair adjusted BRAWLER's *Ace* skill level by setting the maximum number of aircraft in the mental model to these four study values to find a "best" model of pilot capability. By then holding the skill level constant for all Blue (friendly) and Red (hostile) forces and varying the deception tactics used in the scenario, Sinclair estimates that 5 is the "best" value for accurately depicting true pilot performance [13, 26]. That is, when deception tactics are employed an *Ace* pilot should not have unlimited mental model capability.

Furthermore, Sinclair found the explicit modeling of the *Ace* skill level clearly mattered and "the biggest problem with the current blanket use of *Ace* skill level by BRAWLER users is that it gives the BRAWLER pilot an incorrect global view of the battlefield." This "global viewpoint ob-

tained by each pilot ... changes the direction, hence the outcome, of the battle," introducing "significant error into the MOEs at an unacceptable level" [13, 44]. Sinclair went on to propose BRAWLER code changes to more accurately model task overload, target fixation, and the global viewpoint inherent in the *Ace* pilot skill level. It is Sinclair's study that ultimately led to this investigation into the effects of varying BRAWLER pilot skill levels.

2.3 Specific Problem

In recent years, fighter operational readiness has declined due to reduced combat-specific training in support of real world commitments. This reduced pilot capability manifests in a pilot's ability to function in an air-to-air engagement. Less capable pilots demonstrate reduced capabilities under the stress of air-to-air combat. This means reduced situational awareness with slower and less capable decision making. The result is higher loss rates and/or reduced kill rates in air-to-air engagements.

These concerns have prompted inquiries regarding quantification of reduced fighter pilot operational readiness leading to the fundamental question addressed in this thesis:

Is BRAWLER appropriate for quantifying the operational impact of reduced pilot readiness?

To answer this question, we examine the BRAWLER mental model, through various combinations of the pilot skill levels, and examine how changing pilot skill levels impact the standard BRAWLER output measures of effectiveness—Exchange Ratio, Lethality, and Survivability.

2.4 Methodology

2.4.1 Regression Modeling

Regression modeling is a statistical technique for estimating an assumed functional relationship between variables. Given an independent variable x_i or a set of independent variables $\mathbf{X}$, the function

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{1}$$

describes the functional relationship between $\mathbf{X}$ and $\mathbf{y}$, where $\mathbf{y}$ is the response variable of interest, also known as the dependent variable, and $\boldsymbol{\beta}$ represents the expected change in response $\mathbf{y}$ per unit change in $\mathbf{X}$ [9, 17]. Random error is modeled as $\boldsymbol{\varepsilon}$, and includes the effects of other independent variables not modeled in (1). It is also assumed errors are normally distributed random variables, mean 0, variance σ^2.

Generally, exact values of $\boldsymbol{\beta}$ are unknown and must be estimated. The method of least squares produces unbiased estimators, b_j of the β_j's and is typically used to estimate the regression coefficients [9, 17] . Least squares seeks values for the vector $\mathbf{b}$ of b_j's such that the squared difference between the predicted values of

$$\hat{\mathbf{y}} = \mathbf{b}\mathbf{X} \tag{2}$$

and the actual values, $\mathbf{y}$, is minimized. This difference, or residuals,

$$\mathbf{e} = \mathbf{y} - \hat{\mathbf{y}} \tag{3}$$

estimates the functional model error term ε, which naturally implies e should also follow a normal distribution, mean 0, variance σ^2. The least squares estimator (1) is given by the formula

$$\mathbf{b} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\mathbf{y} \tag{4}$$

where

$$\mathbf{b} = \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_k \end{bmatrix}, \tag{5}$$

is a vector of regression coefficient estimates,

$$\mathbf{X} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdots & x_{1k} \\ 1 & x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix}, \tag{6}$$

is redefined as a matrix where x_{ij} represents each of $j = 1, ..., k$ factors sampled across $i = 1, ..., n$ replications (or design points), and

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, \tag{7}$$

is an (n x 1) vector of observations.

A regression model must be adequate and sufficient for use. Adequacy relates to whether underlying model assumptions are satisfied. In particular, is the vector of residuals $\mathbf{e} = \hat{\mathbf{y}} - \mathbf{y}$, or error terms, independent and identically distributed (iid) normal random variables with mean 0 and variance σ^2 (i.e., e $\sim N(\mathbf{0}, \mathbf{I}\sigma^2)$). Residual plots provide a graphical means of checking the normality assumption.

Analysis of Variance (ANOVA) apportions variance between predicted and actual values to discern variance due to error and variance due to the regression model. The mean square error (MSE) provides a measure of the variability due to error. All remaining variance is called mean square regression (MSR) and represents the model variance. Further partitioning of the error into lack of fit error and pure error provides the basis for a statistical Lack of Fit (LOF) Test. Under the normality assumption, the ratio between mean square lack of fit (MSLOF) and mean square pure error (MSPE) has a central F distribution. This relationship provides a test of the significance of a fitted model. A poorly fitted model will follow a non-central F distribution, thereby failing a hypothesis of model adequacy based on a central F distribution test.

Another measure of model sufficiency is the coefficient of multiple determination R^2. R^2 is the proportion of the variability within the observed responses accounted for or explained by the model, or the degree to which the vector of fitted responses $\widehat{\mathbf{y}}$ correspond to the vector of observed responses $\mathbf{y}$. R^2 represents the ratio of the sample variance of the fitted values to the sample variance of the observed values. It turns out that $0 \leq R^2 \leq 1$ and the larger R^2 the better the model fit.

For a more complete presentation on regression, refer to Neter *et al*, *Applied Linear Regression Models* [10]. A particularly useful application of regression is within an overarching experimental approach called Response Surface Methodology (RSM).

2.4.2 Response Surface Methodology

According to Myers and Montgomery, response surface methodology is a collection of statistical and mathematical techniques useful for the exploration and optimization of response surfaces [9, 1]. A response surface is simply a geometric surface representing a function. The utility of this surface is its predictive ability—given a set of inputs (experimental data), what is the expected response and how do we produce a "good" response?

The experimental data consists of the response variables y and the independent variables, $x_1, x_2, ..., x_k$. The relationship between the experimental data takes the general form (1), which is approximated using least squares regression. Usually a low-order polynomial (first-order or second-order) approximation is appropriate. In general, the first-order or linear model is

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon, \tag{8}$$

and the second-order or non-linear model is

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j x_j + \sum_{j=1}^{k} \beta_{jj} x_j^2 + \sum_{i<j} \sum \beta_{ij} x_i x_j + \varepsilon. \tag{9}$$

A second-order model is used to capture any curvature, or non-linearity, present in the response surface.

Generally, RSM follows a three step process—experimental design, data collection, and regression analysis. Having already discussed regression analysis, the next two sections describe experimental design and data collection emphasizing how they relate to this research.

2.4.3 Experimental Design

Designed experiments induce purposeful changes in input variable(s) in order to observe and model the changes in the response(s) [8]. Input variables, or response variables, are known as *factors* and the purposeful changes are the *factor levels* or factor settings examined. In RSM, it is usually convenient to *code* the variable settings rather than use the actual setting values. Coding standardizes the variables making them dimensionless with mean zero. This aids in situations where variables have different dimensional units like inches and pounds. It also promotes orthogonality within the design matrix, which is discussed later. A general formula for coding quantitative variables [4, 107] is

$$x_{ij} = \frac{\xi_{ij} - \xi_{ij0}}{S_{ij}} \; (i = 1, ..., n; j = 1, ..., k) \tag{10}$$

where

x_{ij} is the coded value of the j^{th} observation of factor x_i,

ξ_{ij} is the uncoded values,

ξ_{ij0} is the uncoded average value,

S_{ij} is the half range between the uncoded high and low values.

Non-quantitative variables may also be encoded to represent levels of settings. For instance, high, medium, and low levels easily map to $1, 0,$ and -1 coded values, respectively.

A *design point* is a specific combination of levels for each of the k factors. An experimental design is the schedule of design points investigated in an experiment. A complete or full-factorial design contains all design points, which involves all possible combination of factor levels. Normally, a full factorial design is cost prohibitive, so cheaper yet efficient designs are typically used. These are generally called fractional-factorial designs since the number of design points is typically $\frac{1}{2}, \frac{1}{4}$, or some other fraction of the total design points. With a properly constructed fractional-factorial it is still possible to estimate the hypothesized model, subject to some confounding. Confounding occurs when certain effects, or factors cannot be distinguished from others. This results in some loss of accuracy, although its effect can be minimized by confounding factors not considered important. This loss of accuracy generally takes on two forms—model misspecification (lack of fit) and variance (pure error). Although statistics literature contains an enormous amount of information on experimental design for RSM, Myers and Montgomery feel that the majority of this literature is

concerned with variance-oriented designs—that is, the type of design that ignores model misspecification and assumes that the user specified model is correct [9, 283].

In order to understand variance-oriented designs, consider a situation in which N experiments are conducted using k design factors and a single response y. The first order model for each design point is

$$\hat{y}_i = b_0 + b_1 x_{i1} + b_2 x_{i2} + \cdots + b_k x_{ik} + e_i \; (i = 1, 2, ..., N), \tag{11}$$

or equivalently (2) in matrix terms. A variance-oriented design minimizes the variance of the regression coefficients, $b_j, j = 0, 1, ..., k$. A first order orthogonal design requires that $\mathbf{X}'\mathbf{X}$ be a diagonal matrix. This means all columns of $\mathbf{X}$ must be mutually orthogonal—any two corresponding columns (x_0 corresponds to the first column of $\mathbf{X}$, x_1 the second column, and so on) are linearly independent. Thus, minimum variance estimators of the regression coefficients, $b_j, j = 0, 1, ..., k$, occur when factor levels are set at the coded ± 1 extremes [9, 284].

For second order designs, more emphasis is placed on prediction capability and orthogonality becomes secondary to the scaled prediction variance. Variance of the predicted value $\hat{y}$ is a function of the model, the location of the design variables at which one predicts, and varies from location to location within the design space. It is important for a second-order design to possess a reasonably stable distribution of prediction variance throughout the design region [9, 306]. To this end, Box and Hunter (1957) developed the notion of design rotatability. With a rotatable design, any two points equal distant from the center (of the design) have the same prediction variance [9, 306]. Although, this in itself does not provide stability throughout the design region, the addition of center runs (i.e., multiple design points all of whose factor levels code to 0) stabilizes prediction variance.

In 1960 Box and Behnken developed a family of efficient three-level designs for fitting second order response surfaces. Their designs are based on the construction of balanced incomplete block designs, where a block is defined as the "pairing" together of factors. The blocks are incomplete because not all levels of the factors are represented. For example, the layout of a balanced incomplete block design with four factors and six blocks is given in Table 1. The pairing together of

Table 1. Balanced Incomplete Block Design

	Factor			
	1	2	3	4
Block 1	X	X		
Block 2	X		X	
Block 3	X			X
Block 4		X	X	
Block 5		X		X
Block 6			X	X

factors 1 and 2 in Block 1 implies that factors x_1 and x_2 are paired together in a 2^2 factorial (scaling ± 1) while x_3 and x_4 remain fixed at the center ($= 0$). The same applies for subsequent blocks. [9, 318]. As a result, with $k = 4$ factors, the full design matrix expands to (12). In fact, it turns out that with $k = 4$ factors the design is exactly rotatable. Thus, the BBD is an efficient option with just 24 design points as opposed to the full-factorial design which would require 3^4 or 81 design points. In order to avoid design matrix singularity and provide stability of prediction variance, additional design points, called center runs, are added. The use of 3-5 center runs (zero rows) are recommended for the Box-Behnken Design (BBD) [9, 323]. Each row of (12) represents a design point of factor settings used to obtain the necessary experimental data.

$$
\mathbf{D} = \begin{array}{c}
\begin{matrix} x_1 & x_2 & x_3 & x_4 \end{matrix} \\
\begin{bmatrix}
-1 & -1 & 0 & 0 \\
-1 & 1 & 0 & 0 \\
1 & -1 & 0 & 0 \\
1 & 1 & 0 & 0 \\
\cdots & \cdots & \cdots & \cdots \\
-1 & 0 & -1 & 0 \\
-1 & 0 & 1 & 0 \\
1 & 0 & -1 & 0 \\
1 & 0 & 1 & 0 \\
\cdots & \cdots & \cdots & \cdots \\
-1 & 0 & 0 & -1 \\
-1 & 0 & 0 & 1 \\
1 & 0 & 0 & -1 \\
1 & 0 & 0 & 1 \\
\cdots & \cdots & \cdots & \cdots \\
0 & -1 & -1 & 0 \\
0 & -1 & 1 & 0 \\
0 & 1 & -1 & 0 \\
0 & 1 & 1 & 0 \\
\cdots & \cdots & \cdots & \cdots \\
0 & -1 & 0 & -1 \\
0 & -1 & 0 & 1 \\
0 & 1 & 0 & -1 \\
0 & 1 & 0 & 1 \\
\cdots & \cdots & \cdots & \cdots \\
0 & 0 & -1 & -1 \\
0 & 0 & -1 & 1 \\
0 & 0 & 1 & -1 \\
0 & 0 & 1 & 1
\end{bmatrix}
\end{array} \tag{12}
$$

2.4.4 Data Collection

Collecting data for this analysis involved multiple BRAWLER runs. Due to run times involved in large multi-aircraft scenarios, and a realistic pilot perspective that the basic fighting force of the USAF is a 4-ship, a scenario was developed for a 4 v 4 air combat simulation with the initial setup depicted in Figure 5. Blue represents the friendly force and Red the hostile. The positions Blue 1 through Blue 4 represent four pilots—the flight lead, his wingman, another flight lead, and his wingman, respectively. The same relationship exist for the Red force.

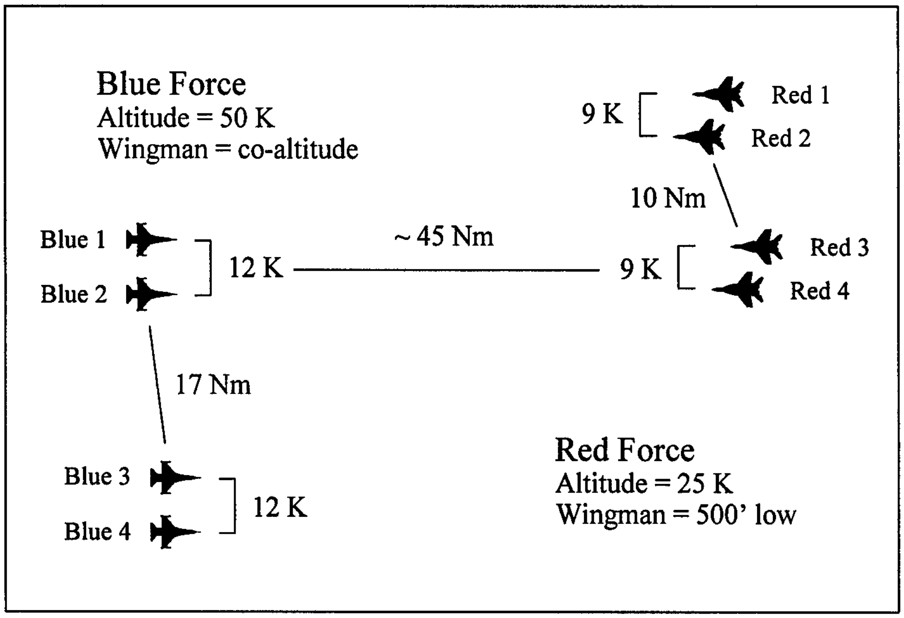

Figure 5. Scenario Setup

The skill level of each pilot represents the design factor with the three discrete, non-quantitative levels—*Ace*, *Pilot*, and *Rookie*—previously described. Blue pilot skill levels were varied while Red pilot skill levels were held constant at an *Ace* level. Factor level settings for *Ace*, *Pilot*, and *Rookie* were coded as $1, 0$, or -1, respectively. The BBD in (12) provided 24 design points. Supplemented by five center design points (all *Pilot* skill level) and the addition of one control point (all *Ace* skill level) gives rise to the final design matrix

$$\mathbf{X} = \left[\begin{array}{ccc} & \vdots & \mathbf{D} \\ & \vdots & \cdots \\ \mathbf{1} & \vdots & \mathbf{0} \\ & \vdots & \cdots \\ & \vdots & \mathbf{1} \end{array}\right],$$

were $\mathbf{1}$ is a column vector of ones representing the constant or intercept term in regression models (8) or (9), $\mathbf{D}$ is the 24 design point BBD in (12) of which the columns represent factor level settings

for Blue 1 through Blue 4, respectively, **0** is the five center design points, and **1** is a row vector of ones corresponding to an all *Ace* (i.e. high) factor level setting design point—a total of 30 design points. Appendix A contains the complete design matrix translated to "BRAWLER-ease."

Each of the 30 design points required an unique **SCNRIO** file, a required BRAWLER input file (see Appendix B for a sample file). Each design point was replicated until 55 error free runs were obtained. Next, reports were generated by post-processing BRAWLER output files to collect the desired responses (MOEs). This involved using a diagnostic feature of BRAWLER called *lprnts*. *Lprnts* are print statements embedded in BRAWLER, originally for diagnostic purposes which are set in the **SCNRIO** file. An array of 240 *lprnt* flags are available and control the output from different routines. Appendix C contains a reference of *lprnts* accessing the pilot's mental model. By turning specific *lprnts* on, data was printed to the output files and subsequently post-processed. Appendix D contains the AWK programming script used to post-process the BRAWLER simulation output. Details of the AWK language can be found in texts by Aho [3]and Robbins [11].

2.5 Implementation

2.5.1 Assumptions

BRAWLER is almost exclusively ran in a classified environment. This is due to the nature of the weapons systems being modeled. Current limitations at AFIT prevent the use of a classified version of BRAWLER. The Survivability/Vulnerability Information Analysis Center (SURVIAC) was able to provide an unclassified version (Version 6.3 – Unclassified) of BRAWLER which was subsequently installed on a Silicon Graphics workstation. Our simulation runs used the unclassified database, **SCNRIO** file, and production rules distributed with BRAWLER.

Unfortunately, the unclassified production rules force a pilot to be overly aggressive in a "fight to the death" ignoring normal disengagement conditions, such as a low fuel (Bingo) state. The re-

sult is aircraft running out of fuel and subsequently crashing providing an artificial kill (ground kill) and biasing of the data. To minimize the biasing, sample runs were made at different simulation run lengths to determine a run length that would capture the effect of disengagement by halting BRAWLER near Bingo fuel, thus preventing ground kills. A simulation time of 600 seconds provided the best trade-off.

Another undesirable side effect of the unclassified production rules is the inability to accurately model the interaction within a 4-ship. This resulted in the 4-ships being modeled as two 2-ships.

2.5.2 Measures of Effectiveness

The three measures of effectiveness that we are concerned with are Exchange Ratio, Lethality, and Survivability of the Blue forces. Exchange Ratio is defined as the ratio of hostile losses to friendly losses.

$$Exchange\ Ratio = \frac{Losses_{hostile}}{Losses_{friendly}} \tag{13}$$

Lethality comes in many flavors, but is defined here on a per engagement basis as the hostile losses over the number of engagements within each design point (i.e., across all 55 replications).

$$Lethality = \frac{Lossses_{hostile}}{N_{engagements}} \tag{14}$$

Survivability is similarly defined on a per engagement basis as the number of friendly minus the friendly losses over the number of engagements.

$$Survivability = \frac{N_{friendly} - Losses_{friendly}}{N_{engagements}} \tag{15}$$

All three MOEs where calculated by using AWK scripts to post process the BRAWLER log files which contain the *lprnt* output. In addition to the default set, *lprnts* 33 130 176 201 256 were turned on (See Appendices C and D for further details). Table 2 summarizes the experimental design and data collected for each MOE.

Table 2. Design Matrix and MOEs

Design Pt	*Blue 1* x_1	*Blue 2* x_2	*Blue 3* x_3	*Blue 4* x_4	*Exchange Ratio*	*Lethality*	*Survivability*
1	ROOKIE	ROOKIE	PILOT	PILOT	18.3333	3.00	3.84
2	ROOKIE	ACE	PILOT	PILOT	18.1000	3.29	3.82
3	ACE	ROOKIE	PILOT	PILOT	17.4545	3.49	3.80
4	ACE	ACE	PILOT	PILOT	38.4000	3.49	3.91
5	PILOT	PILOT	ROOKIE	ROOKIE	11.3125	3.29	3.71
6	PILOT	PILOT	ROOKIE	ACE	16.8182	3.36	3.80
7	PILOT	PILOT	ACE	ROOKIE	14.4615	3.42	3.76
8	PILOT	PILOT	ACE	ACE	48.0000	3.49	3.93
9	ROOKIE	PILOT	PILOT	ROOKIE	26.1429	3.33	3.87
10	ROOKIE	PILOT	PILOT	ACE	23.3750	3.40	3.85
11	ACE	PILOT	PILOT	ROOKIE	13.0667	3.56	3.73
12	ACE	PILOT	PILOT	ACE	20.3000	3.69	3.82
13	PILOT	ROOKIE	ROOKIE	PILOT	19.3330	3.16	3.84
14	PILOT	ROOKIE	ACE	PILOT	19.7000	3.58	3.82
15	PILOT	ACE	ROOKIE	PILOT	31.6667	3.45	3.89
16	PILOT	ACE	ACE	PILOT	40.0000	3.64	3.91
17	ROOKIE	PILOT	ROOKIE	PILOT	34.8000	3.16	3.91
18	ROOKIE	PILOT	ACE	PILOT	23.1250	3.36	3.85
19	ACE	PILOT	ROOKIE	PILOT	22.0000	3.20	3.85
20	ACE	PILOT	ACE	PILOT	13.2000	3.60	3.73
21	PILOT	ROOKIE	PILOT	ROOKIE	14.3630	2.87	3.80
22	PILOT	ROOKIE	PILOT	ACE	20.7778	3.40	3.84
23	PILOT	ACE	PILOT	ROOKIE	47.0000	3.42	3.93
24	PILOT	ACE	PILOT	ACE	51.2500	3.73	3.93
25	PILOT	PILOT	PILOT	PILOT	15.2308	3.60	3.76
26	PILOT	PILOT	PILOT	PILOT	23.3750	3.40	3.85
27	PILOT	PILOT	PILOT	PILOT	33.5000	3.65	3.89
28	PILOT	PILOT	PILOT	PILOT	24.5000	3.56	3.85
29	PILOT	PILOT	PILOT	PILOT	13.4286	3.42	3.75
30	ACE	ACE	ACE	ACE	32.8333	3.58	3.89

2.5.3 BRAWLER Runs

Figures 6, 7, and 8 provide scatter plots of the BRAWLER runs for Exchange Ratio, Lethality, and Survivability, respectively. The horizontal axis represents the design point, or skill level combination, of a particular run with the MOE plotted on the vertical axis. The relative vertical spacing of the responses illustrates the variability of the data and suggests an appropriate level of stochastic behavior in the model. Exchange Ratio exhibits the greatest variability and Survivability the least. A horizontal line has been drawn through the all *Ace*-level control point (design point 30) as a benchmark. These plots demonstrate the general trend for an all *Ace*-level 4-ship to outperform other combinations of pilot skill level, as expected. The combinations that outperformed the all *Ace*-level (the points above the line) have been labeled for convenience. For example, a PPAA represents a skill level combination of Pilot, Pilot, Ace, Ace for Blue 1 through Blue 4, respectively. A complete reference of skill level combinations for all design points can be found in Table 2.

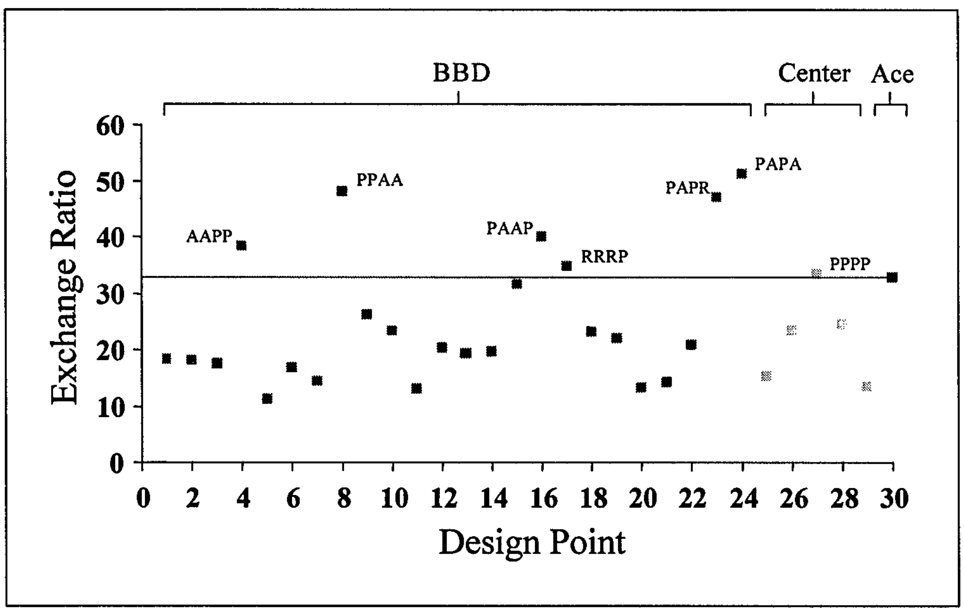

Figure 6. Exchange Ratio – Scatter Plot

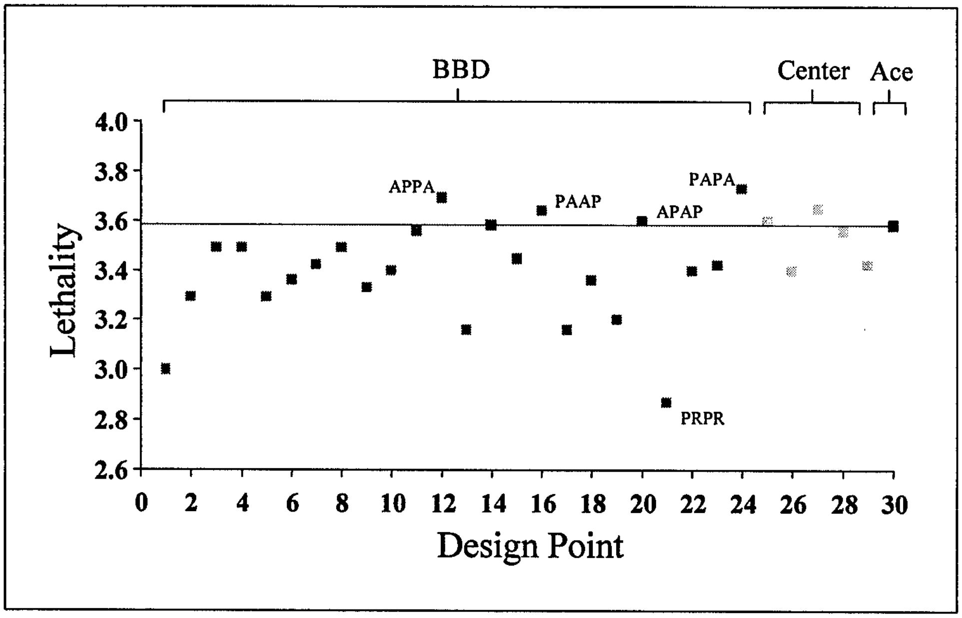

Figure 7. Lethality – Scatter Plot

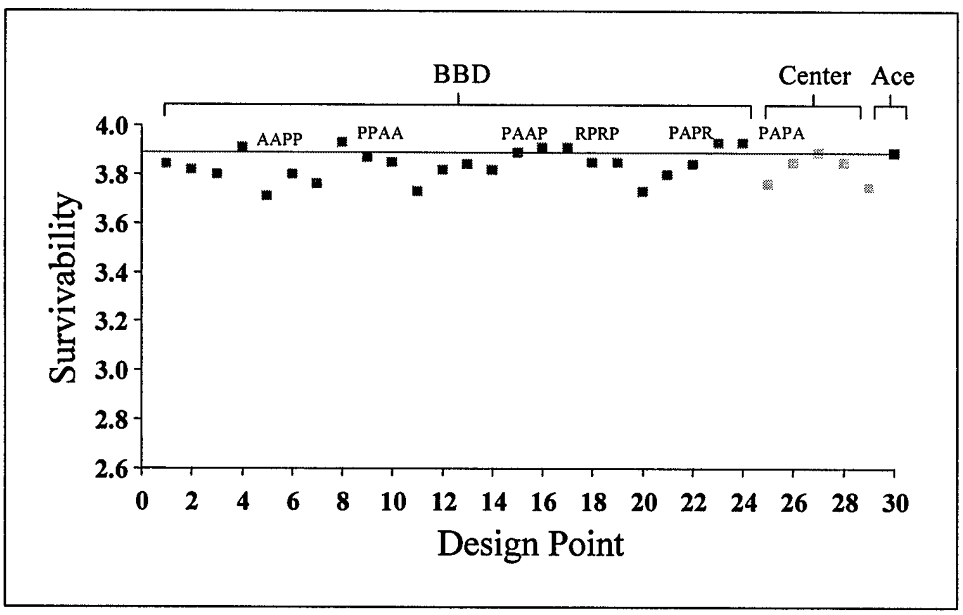

Figure 8. Survivability – Scatter Plot

2.5.4 Regression Models

The model of primary concern in our analysis is the first or second order statistical model. The statistical model is a parsimonious model of the statistically significant factors and factor interactions and can be derived through statistical testing and stepwise regression. For comparison purposes we will also define a practical model. Our practical model encompasses the real world interactions. In the 4 v 4 scenario modeled, all flight members should significantly affect the outcome, along with in-flight communications (interactions) between Blue 1 & 2, Blue 1 & 3, and Blue 3 & 4. We first describe each of three models, one for each MOE, and then discuss the implications of the models with respect to varied pilot skill levels in BRAWLER. The first MOE examined is Exchange Ratio.

2.5.4.1 Exchange Ratio

Computing Exchange Ratio resulted in the following vector of responses from Table 2:

$$\mathbf{y} = \begin{bmatrix} 18.3333 \\ 18.1000 \\ 17.4545 \\ 38.4000 \\ 11.3125 \\ 16.8182 \\ 14.4615 \\ 48.0000 \\ 26.1429 \\ 23.3750 \\ 13.0667 \\ 20.3000 \\ 19.3333 \\ 19.7000 \\ 31.6667 \\ 40.0000 \\ 34.8000 \\ 23.1250 \\ 22.0000 \\ 13.2000 \\ 14.3630 \\ 20.7778 \\ 47.0000 \\ 51.2500 \\ 15.2308 \\ 23.3750 \\ 33.5000 \\ 24.5000 \\ 13.4286 \\ 32.8333 \end{bmatrix}$$

Using JMP© PC software (produced by SAS Institute, Inc.) as our analysis engine the parameter estimates for our practical model are given in Table 3 with the resulting practical model

$$\hat{y} = 24.27 - 2.38x_1 + 8.95x_2 + 1.12x_3 + 3.76x_4 + 3.02x_1x_2 - 1.55x_1x_3 + 7.74x_3x_4 \qquad (16)$$

Review of the parameter estimates indicate that x_2 is the only statistically significant factor at an α level of 0.1 (Prob>|t| value less than 0.1). Further analysis into interactions and curvature yields the parameter estimates in Table 4 with the resulting parsimonious statistical model

$$\hat{y} = 24.54 + 9.60x_2 \tag{17}$$

Surprisingly, results indicate no statistically significant interaction or curvature.

The residual plot in Figure 9 shows no distinct pattern, so the regression model appears adequate. Table 5 provides the LOF results with the Prob>F value indicating that the statistical model is sufficient at the $\alpha = 0.1$ level. However, as seen in Table 6, the regression model accounts for only a small proportion of the variability within the observed responses, since $R^2 = 0.33$. Next we consider the effects on lethality.

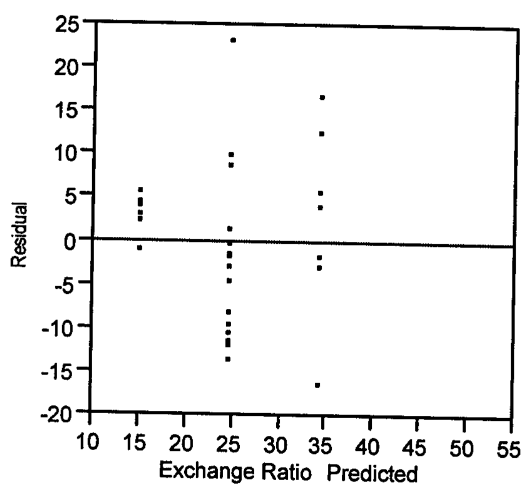

Figure 9. Exchange Ratio – Residual Analysis Plot

Table 3. Exchange Ratio - Practical Model Parameter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	24.273232	1.750804	13.86	<.0001	20.642315	27.904148
X1	-2.378815	2.689636	-0.88	0.3860	-7.956735	3.1991048
X2	8.9470264	2.689636	3.33	0.0031	3.3691063	14.524947
X3	1.1221097	2.689636	0.42	0.6806	-4.45581	6.7000298
X4	3.7569681	2.689636	1.40	0.1764	-1.820952	9.3348882
X1*X2	3.0220042	4.463692	0.68	0.5055	-6.235053	12.279062
X1*X3	-1.553946	4.463692	-0.35	0.7311	-10.811	7.7031118
X3*X4	4.7355042	4.463692	1.06	0.3002	-4.521553	13.992562

Table 4. Exchange Ratio - Statistical Model Parmeter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	24.54173	1.707957	14.37	<.0001	21.043166	28.040294
X2	9.5958977	2.594572	3.70	0.0009	4.2811975	14.910598

Table 5. Exchange Ratio - Lack of Fit Test

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	1	224.2178	224.218	2.7271
Pure Error	27	2219.8764	82.218	Prob>F
Total Error	28	2444.0943		0.1102
				Max RSq
				0.3898

Table 6. Exchange Ratio - Summary of Fit

Summary of Fit

RSquare	0.328191
RSquare Adj	0.304198
Root Mean Square Error	9.342863
Mean of Response	24.86159
Observations (or Sum Wgts)	30

2.5.4.2 *Lethality*

Computing Lethality resulted in the following vector of responses from Table 2:

$$\mathbf{y} = \begin{bmatrix} 3.00 \\ 3.29 \\ 3.49 \\ 3.49 \\ 3.29 \\ 3.36 \\ 3.42 \\ 3.49 \\ 3.33 \\ 3.40 \\ 3.56 \\ 3.69 \\ 3.16 \\ 3.58 \\ 3.45 \\ 3.64 \\ 3.16 \\ 3.36 \\ 3.20 \\ 3.60 \\ 2.87 \\ 3.40 \\ 3.42 \\ 3.73 \\ 3.60 \\ 3.40 \\ 3.65 \\ 3.56 \\ 3.42 \\ 3.58 \end{bmatrix}$$

The parameter estimates for our practical model are given in Table 7 with the resulting practical model

$$\hat{y} = 3.41 + 0.11x_1 + 0.12x_2 + 0.11x_3 + 0.09x_4 - 0.11x_1x_2 + 0.02x_1x_3 - 0.03x_3x_4 \quad (18)$$

Review of the parameter estimates indicate that only the main effects x_1, x_2, x_3, x_4 are statistically significant factors at an α level of 0.1. Continued analysis into interactions and curvature yields the parameter estimates in Table 8. Results indicate no significant interaction or curvature present at the $\alpha = 0.1$ level. Thus, the parsimonious statistical model becomes

$$\hat{y} = 3.41 + 0.11x_1 + 0.11x_2 + 0.10x_3 + 0.08x_4 \tag{19}$$

with all factors statistically significant at an α level of 0.1.

In checking model adequacy, a review of the residual plot in Figure 10 shows no distinct pattern, so the model appears adequate. Table 9 shows the results of the LOF Test for model sufficiency. The Prob>F value indicates that the statistical model is sufficient at the $\alpha = 0.1$ level. Examining the coefficient of multiple determination R^2 in Table 10 indicates that the regression model accounts for a fair proportion of the variability within the observed responses since $R^2 = 0.55$. Lastly, we consider the effects on survivability.

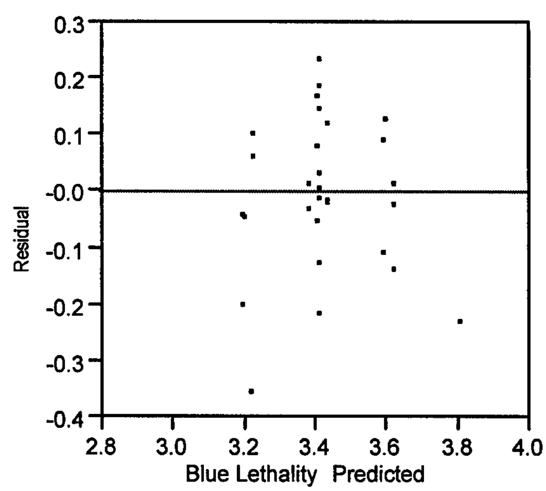

Figure 10. Lethality – Residual Analysis Plot

Table 7. Lethality - Practical Model Parameter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	3.4095251	0.026647	127.95	<.0001	3.3542625	3.4647877
X1	0.113019	0.040936	2.76	0.0114	0.028123	0.197915
X2	0.115519	0.040936	2.82	0.0099	0.030623	0.200415
X3	0.1113523	0.040936	2.72	0.0125	0.0264564	0.1962483
X4	0.0871857	0.040936	2.13	0.0446	0.0022897	0.1720816
X1*X2	-0.105943	0.067937	-1.56	0.1332	-0.246835	0.0349494
X1*X3	0.016557	0.067937	0.24	0.8097	-0.124335	0.1574494
X3*X4	-0.033443	0.067937	-0.49	0.6274	-0.174335	0.1074494

Table 8. Lethality - Statistical Model Parmeter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	3.4064286	0.026493	128.58	<.0001	3.3518656	3.4609915
X1	0.1055357	0.040424	2.61	0.0151	0.0222825	0.1887889
X2	0.1080357	0.040424	2.67	0.0131	0.0247825	0.1912889
X3	0.103869	0.040424	2.57	0.0165	0.0206159	0.1871222
X4	0.0797024	0.040424	1.97	0.0598	-0.003551	0.1629555

Table 9. Lethality - Lack of Fit Test

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	21	0.47290262	0.022519	1.8338
Pure Error	4	0.04912000	0.012280	Prob>F
Total Error	25	0.52202262		0.2957
				Max RSq
				0.9574

Table 10. Lethality - Summary of Fit

Summary of Fit

RSquare	0.5476
RSquare Adj	0.475216
Root Mean Square Error	0.144502
Mean of Response	3.419667
Observations (or Sum Wgts)	30

2.5.4.3 *Survivability*

Computing Survivability resulted in the following vector of responses from Table 2:

$$\mathbf{y} = \begin{bmatrix} 3.84 \\ 3.82 \\ 3.80 \\ 3.91 \\ 3.71 \\ 3.80 \\ 3.76 \\ 3.93 \\ 3.87 \\ 3.85 \\ 3.73 \\ 3.82 \\ 3.84 \\ 3.82 \\ 3.89 \\ 3.91 \\ 3.91 \\ 3.85 \\ 3.85 \\ 3.73 \\ 3.80 \\ 3.84 \\ 3.93 \\ 3.93 \\ 3.76 \\ 3.85 \\ 3.89 \\ 3.85 \\ 3.75 \\ 3.89 \end{bmatrix}$$

The parameter estimates for our practical model are given in Table 11 with the resulting practical model

$$\hat{y} = 3.84 - 0.03x_1 + 0.04x_2 - 0.001x_3 + 0.03x_4 + 0.03x_1x_2 - 0.02x_1x_3 + 0.02x_3x_4 \quad (20)$$

Review of the parameter estimates indicate that main effects x_2 and x_4 are each statistically significant at an α level of 0.1 although x_1 may be close enough to warrant consideration. Further analysis into interactions and curvature yields the parameter estimates in Table 12. Note the presence of curvature as a result of the statistically significant x_2^2 quadratic term at an α level of 0.1. Thus, the resulting parsimonious statistical model becomes

$$\hat{y} = 3.82 - 0.03x_1 + 0.04x_2 + 0.03x_4 + 0.04x_2^2 \tag{21}$$

A review of the residual analysis plot in Figure 11 shows no discernible pattern. Once again the model appears adequate. Table 13 shows the results of the LOF Test. Since the Prob>F value exceeds the specified α significance level of 0.1 the statistical model is sufficient. The value of R^2 in Table 14 implies that the regression model only accounts for a small proportion of the variability within the observed responses, since $R^2 = 0.44$.

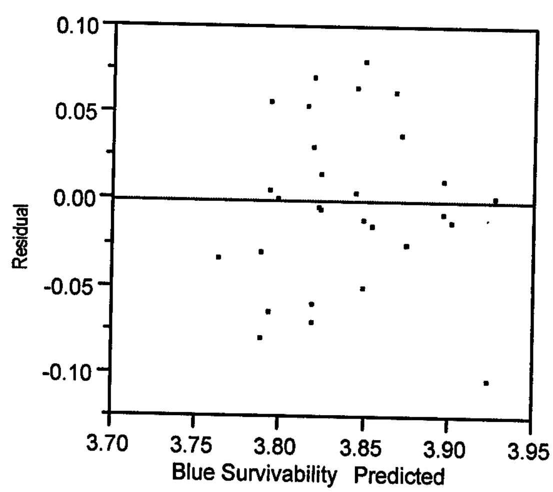

Figure 11. Survivability – Residual Analysis Plot

Table 11. Survivability - Practical Model Parameter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	3.8354274	0.010443	367.27	<.0001	3.8137698	3.857085
X1	-0.02605	0.016043	-1.62	0.1187	-0.059321	0.0072206
X2	0.0364496	0.016043	2.27	0.0332	0.0031785	0.0697206
X3	-0.00105	0.016043	-0.07	0.9484	-0.034321	0.0322206
X4	0.0297829	0.016043	1.86	0.0768	-0.003488	0.0630539
X1*X2	0.0293487	0.026625	1.10	0.2822	-0.025868	0.084565
X1*X3	-0.018151	0.026625	-0.68	0.5025	-0.073368	0.037065
X3*X4	0.0168487	0.026625	0.63	0.5334	-0.038368	0.072065

Table 12. Survivability - Statistical Model Parmeter Estimates

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%
Intercept	3.8182353	0.01232	309.93	<.0001	3.7928623	3.8436083
X1	-0.025885	0.014198	-1.82	0.0803	-0.055126	0.0033555
X2	0.0366146	0.014198	2.58	0.0162	0.0073737	0.0658555
X4	0.0299479	0.014198	2.11	0.0451	0.000707	0.0591888
X2*X2	0.0417126	0.018798	2.22	0.0358	0.002998	0.0804272

Table 13. Survivability - Lack of Fit Test

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	15	0.03020591	0.002014	0.5871
Pure Error	10	0.03430000	0.003430	Prob>F
Total Error	25	0.06450591		0.8299
				Max RSq
				0.7036

Table 14. Survivability - Summary of Fit

Summary of Fit

RSquare	0.442649
RSquare Adj	0.353473
Root Mean Square Error	0.050796
Mean of Response	3.837667
Observations (or Sum Wgts)	30

2.6 Interpretation

2.6.1 Practical Model Definition

As previously stated, a purpose of this research is to objectively assess the BRAWLER model. This assessment is framed in terms of a hypothesized "practical" model and an "actual" model of pilot influences on air combat outcomes.

The practical model is an operationally based assessment and includes the factors one should expect to see in a regression model of air combat factors and engagement outcomes. By comparing the practical model to the actual regression model derived from the experiment, we can gain insight into not only how various combinations of BRAWLER pilot skill levels affect the MOEs, but also whether the results are reasonable. Two hypothesized models are presented. The first illustrates the current USAF employment doctrine of a 4-ship as the basic fighting element. The second, two 2-ship flights, was actually employed here to accommodate BRAWLER's unclassified production rules. This change is reasonable given that a 4-ship is the result of melding two 2-ships.

Figure 12 depicts a 4-ship practical model. Note the relative size of the airframes (silhouette size indicates relative importance) and the interaction, or communication, between pilots (represented by lightning bolts). For example, Blue 1 is twice the size of Blue 3 and four times the size of the wingmen Blue 2 and Blue 4. That is, one might expect the relative importance of Blue 1 in determining the outcome of an engagement, or MOE, to be twice that of Blue 3 and four times that of either wingman. Note also that Blue 3 is twice as influential as any wingman. Similarly, the interaction between Blue 1 & 3 should be twice as important as the interaction between Blue 1 & 2 or Blue 3 & 4.

To better understand the hypothesized relationships, consider the in-flight leadership structure, responsibility, and supporting/engaged fighter roles in a typical 4-ship. An inherent flight

lead/wingman leadership structure, or relationship, exists within any 2-ship. When melding two 2-ships to create the USAF basic fighting unit, a 4-ship, this same leadership structure exists between the flight leads of the respective 2-ships. The overall leader is referred to as the flight lead and the subordinate leader is referred to as the element lead. The bottom line is there is only one leader making tactical and targeting decisions for the 4-ship. This leadership structure is reflected in the in-flight responsibilities and engaged/supporting roles of the flight members.

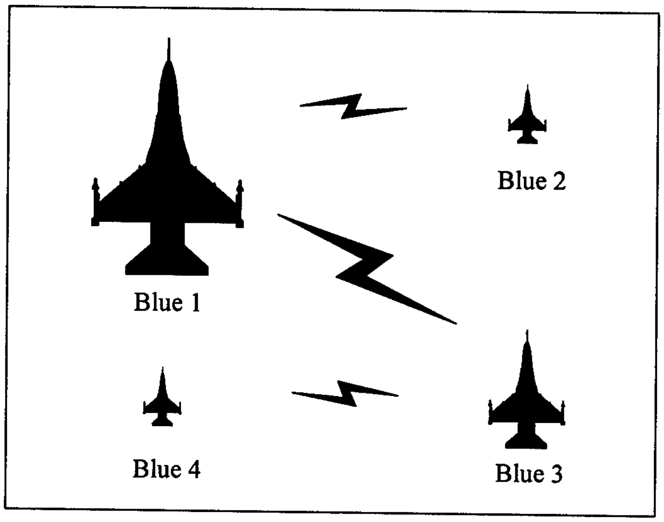

Figure 12. Practical Model – 4-ship

An example of in-flight responsibilities is given in Table 15. Notice how the flight lead, Blue 1, is responsible for navigation. In other words, getting the flight to the fight. Blue 1 and Blue 3, the flight leaders, share the radar search responsibility and thus targeting responsibilities for their respective flight. But, as we say in the business, the flight lead (Blue 1) has the hammer; Blue 1 makes targeting decisions for the 4-ship flight.

This hierarchy is even more clearly defined in engaged/supporting fighter roles. The engaged fighter maneuvers with the intent of achieving a kill. By the nature of the responsibilities outlined

above, this is usually the one with the radar contact, that is, the flight leaders. On the other hand, the supporting fighter duties include sanitizing (watching for additional hostiles) the area, maintaining visual contact with the fight, and maintaining overall situational awareness to include fuel state and exit avenues. It should be clear that the flight leaders really determine the outcome of an engagement.

Table 15. Typical 4-ship Responsibilites

	Blue			
Responsibility	1	2	3	4
1st	GRD Clearance	GRD Clearance	GRD Clearance	GRD Clearance
2nd	Navigation	Formation	Formation	Formation
3rd	Radar Search	Visual Lookout	Radar Search	Visual Lookout
4th	Visual Lookout	Radar Search	Visual Lookout	Radar Search

Figure 13 portrays the dual 2-ship practical model used as the basis of comparison in this thesis. The relative influence displayed between Blue 1 & 3 in the 4-ship practical model in Figure 12 is now expected within each individual flight. This means both flight leads (Blue 1 & 3) should play relatively equal roles with both twice as important as their wingman (Blue 2 & 4, respectively) in determining the outcome of an engagement. The primary difference between Figures 12 and 13 is the interaction between Blue 1 & 3. The interaction between each flight lead and their wingman becomes crucial carrying the same relative influence as the 4-ship interaction between Blue 1 & 3. In Figure 13 this is depicted by relative equal sizing of the lighting bolt, or interaction, between Blue 1 & 2 and Blue 3 & 4, which is on the order of five times the relative importance of the interaction between 1 & 3 (colored gray to denote lack of significance). Figure 13 is next used as a basis for examining the RSM results previously presented. By convention, each of Figures 14-16 will reproduce Figure 13 on the left while the actual model will be depicted on the right for ease of comparison.

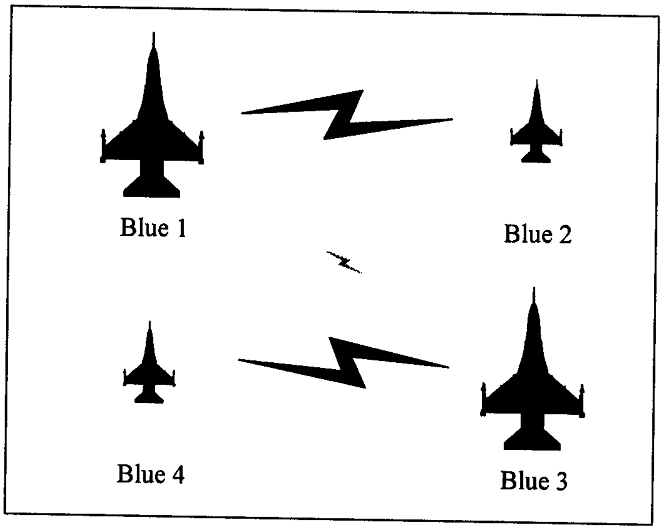

Figure 13. Practical Model – Two 2-ships

2.6.2 Exchange Ratio – Actual Model

Figure 14 compares the hypothesized 2-ship model to the exchange ratio results, again using relative sizing. Clearly, the hypothesized relationships are reversed. Blue 2 exhibits the dominant influence. In regression coefficient terms, Blue 2's importance is two and a half times that of Blue 4, four times that of Blue 1, and eight times that of Blue 3. In fact, Blue 2 is the only statistically significant regression factor as indicated here in black with all non-statistically significant factors denoted in gray. As for intra-flight interaction or communication, the interaction between Blue 3 & 4 is nearly three times that of Blue 1 & 2 and five times that of Blue 1 & 3. Although the relative influence exhibited by these interactions is largely expected, the lack of statistical significance is surprising and counterintuitive. Based upon in-flight responsibilities and engaged/supporting fighter roles, one should expect the flight leads (Blue 1 and Blue 3) to have the most influence such as depicted in Figure 13. Furthermore, we would expect the intra-flight interaction, or communication, to play a significant role. Two-ship targeting and mutual support should not permit anything else. From an interaction perspective, this formation may as well have been four single-ships.

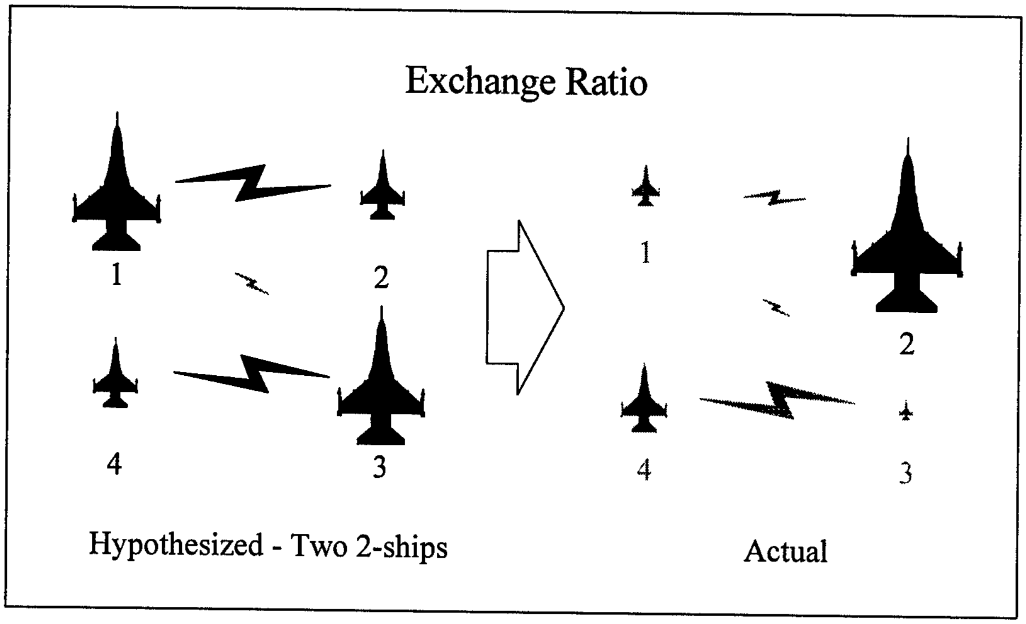

Figure 14. Exchange Ratio – Practical vs Actual

2.6.3 Lethality – Actual Model

Figure 15 compares the hypothesized 2-ship model to the lethality results, with a different outcome. All four pilots have nearly equal influence. That is, they have approximately the same number of kills per engagement, resulting in near equal contribution to the lethality MOE. Blue 2 is only 1.1 times as effective as Blue 1 & 3 and 1.3 times as effective as Blue 4. Although this is not as hypothesized, it is less suspect than exchange ratio. With BVR missiles and good targeting as the result of good communication, it is quite likely that near equal lethality numbers could exist. In other words, the results are believable and we would not necessarily consider them suspect. It is worth noting that USAF operational readiness inspection (ORI) results closely parallel the practical model relationships with the flight lead, Blue 1, obtaining the greatest percentage of the kills followed by the element lead, Blue 3, and lastly the wingmen, Blue 2 & 4. Inter-flight communication in Figure 15 presents a different story. Here, the interaction between Blue 1 & 2 is 3.6 times that of 3 & 4

and five and a half times that of Blue 1 & 3. Although some increase in the Blue 1 & 2 interaction makes sense, since this flight is almost always first to the fight, the relative magnitude over the interaction of Blue 3 & 4 is too large. Finally, all inter-flight activity falls out. In reality, inter-flight communication is crucial. As stated earlier, in order to get equal numbers in lethality–one needs good targeting which is the direct result of good communication. Finally, survivability provided interesting results as well.

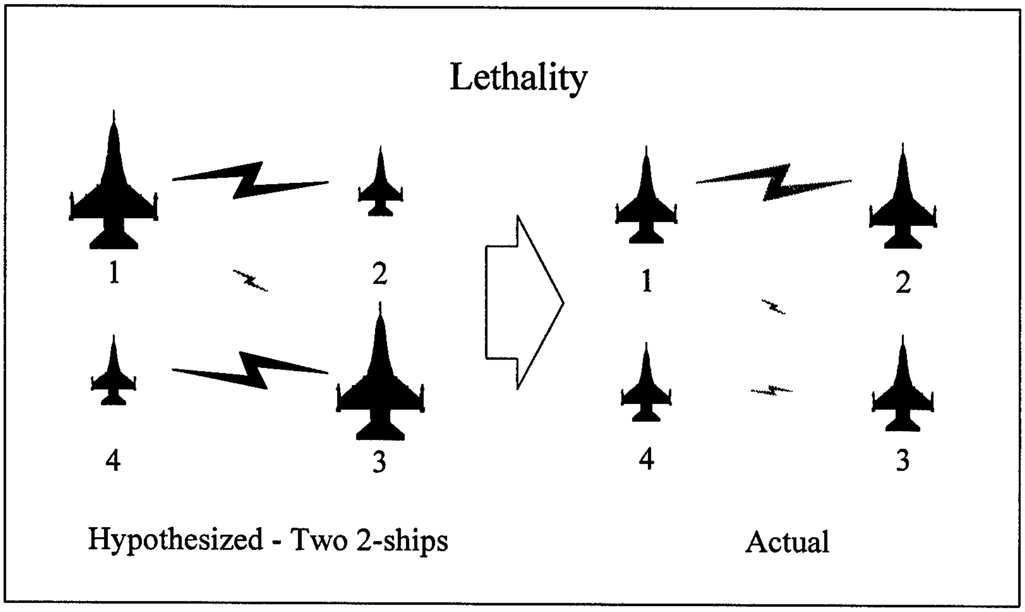

Figure 15. Lethality – Hypothesized vs Actual

2.6.4 Survivability – Actual Model

Figure 16 compares the hypothesized 2-ship model to the survivability results. Blue 2 is again the dominant player, 1.3 times as important as Blue 1 & 4 and forty times that of Blue 3. Also present in Blue 2 effects is a non-linear influence on survivability (indicated by a curved arrow under the 2). An argument could be made that a wingman providing good mutual support is worth their weight in gold, which these results suggest. In reality, a flight lead is more likely to save a

wingman than vice versa and as such, Blue 3's lack of statistically significant influence stands in contrast. Again, the practical model is more representative of the real world. Another alarming result is the negative coefficient for Blue 1 in the statistical model (21). This implies that survivability actually decreases as Blue 1's skill level increases. Review of flight communication indicates a near even distribution with the interaction between Blue 1 & 2 only 1.5 times that of Blue 1 & 3 and 3 & 4. The relative size of the interaction between Blue 1 & Blue 3 could indicate one flight's survivability is inter-dependent on the other flight. Although reasonable, BRAWLER results are still not what we would expect given the near equal distribution in lethality and the lack of statistically significant interactions. Since communications, such as defensive reaction calls, play as large a roll in survivability, these results are suspect.

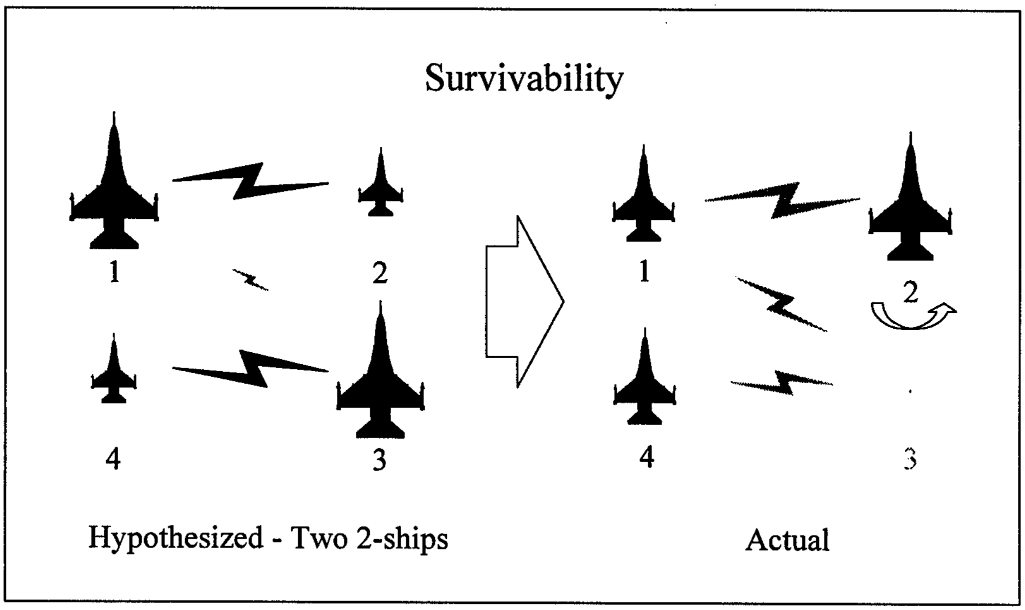

Figure 16. Survivability – Practical vs Actual

2.7 Results and Conclusion

This thesis examined BRAWLER's ability to reasonably quantify the impact of reduced pilot readiness in air-to-air combat. Specifically, we experimentally investigated the influence of varied pilot skill levels on three BRAWLER measures of effectiveness—Exchange Ratio, Lethality, and Survivability. Scatter plots of individual BRAWLER runs suggests an appropriate level of stochastic behavior in the model. These plots also demonstrate the general trend for an all *Ace*-level 4-ship to outperform other combinations of pilot skill level. However, comparison of the statistical results to a practical model revealed suspect behavior in BRAWLER's modeling of pilot skill level. Blue 2, a wingman, exhibited the most influence in all three MOEs. Also exhibited in all three MOEs was a lack of significance of the interactions between flight members. These results should parallel the practical model in which the dominant players are the flight leads, Blue 1 & Blue 3, and significant intra-flight interactions exist. They do not and appear suspect. Naturally, this study provides a limited view of BRAWLER due to our reliance on unclassified data and production rules. The immediate research agenda is to replicate the methodology developed in this research in a realistic, classified environment. Thus, further investigation is warranted before making any claims as to the appropriateness of BRAWLER in quantifying the operational impact of reduced pilot readiness. As it stands now, quantification through the use of pilot skill level does not appear appropriate.

Chapter 3 - Conclusion and Discussion

3.1 Summary

Real world commitments coupled with dramatic force cuts has greatly increased the ops tempo of our combat units. Despite this increase, overall readiness is declining due to reduced combat-specific training. Increasing concern over the United States military's overall fighter capability has prompted inquiries regarding the quantification of reduced fighter pilot operational readiness and its potential impact on future military operations. After all, pilots with reduced capabilities will exhibit lower situational awareness and less capable decision making resulting in higher loss rates and/or reduced kill rates in air-to-air engagements. Accurate modeling and simulation can help provide insight into quantifying reduced operational readiness. BRAWLER is the air-to-air combat simulation model of choice due to its unique modeling of the pilot mental process and situation awareness. The question now becomes, "Is BRAWLER appropriate for quantifying the operational impact of reduced pilot readiness?" To answer this question, we explore one of the ways in which BRAWLER models limited pilot capability—pilot skill level. Pilot skill level was modeled at three discrete levels (*Ace, Pilot,* and *Rookie)*, each of which varies the number of aircraft a pilot can track in his "mental model" (i.e. unlimited, 5, and 3, respectively).

The primary objectives of this thesis were (1) determine the impact of different combinations of *Rookie*, *Pilot*, and *Ace* skill levels on standard BRAWLER output MOEs and (2) to investigate any unique underlying factors that surface when varying pilot skill level in BRAWLER. RSM was chosen as our analysis technique to quantify the sensitivity of BRAWLER to pilot skill level. RSM encompassed three phases—experimental design, data collection, and regression analysis. A BBD was selected for its low estimator variance and efficiency characteristics and was then used to determine the factor level combinations studied in this thesis. A 4 v 4 air-to-air combat scenario was

developed with the BBD used to determine the Blue force settings while the Red force was maintained at an *Ace* skill level. Multiple runs of BRAWLER provided data on three MOEs—Exchange Ratio, Lethality, and Survivability. Subsequent regression analysis of the data provided insight into those factors most influential in determining the MOEs. Hypothesized practical models were developed as representative of real world skill level influence and its interactions. Comparison of this practical model to the actual model of experimental results guided the final interpretation of the experimental data.

3.2 Discussion

Scatter plots of individual BRAWLER runs demonstrate the general trend for an all *Ace*-level 4-ship to outperform other combinations of pilot skill level. However, interpretation of the three MOEs lead us to believe BRAWLER's modeling of pilot skill level is suspect. Two distinct trends emerged from the data—the dominance of Blue 2 and the lack of significance of inter-flight interactions. The repeated conclusion— that each MOE was most sensitive to the skill level of Blue 2—is alarming. This goes against the very nature of the leadership structure (flight lead, wingman), in-flight responsibilities, and engaged/supporting fighter roles inherent in a 2-ship, let alone a 4-ship fighting formation. The lack of significance of inter-flight interactions can somewhat be explained by the BRAWLER production rules. The unclassified production rules are set up to cause a "fight to the death." As a result, a flight lead's decision to disengage for reasons like fuel or undesirable force ratios is essentially overruled. What is most disturbing is the lack of any statistically significant intra-flight communications, or interactions. Accounting for limitations of unclassified production rules, we might expect to see a decrease in significance, but not the total lack of significance observed. The bottom line is BRAWLER's modeling of pilot skill level is highly suspect and bears further analysis.

Due to the uncharacteristic results, our second thesis objective was not fully explored. Instead, it has been deferred until we can ascertain whether BRAWLER exhibits the same behavior using the classified data set. In other words, we need to determine if the results are unique to the unclassified data set. If so, further studies involving BRAWLER should avoid use of the unclassified data set until it is more representative of real world behavior. There is reason to believe that since the community predominately uses the classified data set, behavior anomalies in unclassified data set have not received the same attention and may be unwarranted. If the results are not unique, further investigation is warranted.

If BRAWLER is to be used to quantify reduced operational readiness in the air-to-air environment, the implications of our results require, at the very least, the experiment be repeated using a classified data set with more accurate production rules. Both the 4-ship and 2-ship scenario should be examined to determine if BRAWLER exhibits the same uncharacteristic behavior.

At this time it is not possible to answer the general question "Is BRAWLER appropriate for quantifying the operational impact of reduced pilot readiness?" However, given the assumptions presented in our analysis (primarily the use of the unclassified data set and production rules) BRAWLER exhibits uncharacteristic behavior in modeling pilot skill level and therefore, considered inappropriate.

3.3 Additional Research

BRAWLER models limited pilot capabilities through a pilot skill level setting, inherent bias, and induced goal fixation. This thesis effort touched on one, pilot skill level. The effects of inherent bias and induced goal fixation could also provide insight into the issue of mission readiness (in the context of air-to-air combat proficiency) of the pilot force.

By far, the biggest hurdles in accomplishing this research were installation problems associated with BRAWLER and its user interface. In this day and age, the installation process should be trivial and not require experts to accomplish. Needless to say, this is not the case. There is still an unresolved issue whereby the simulation intermittently hangs, the cause of which is unknown. A "monitor" script was written to monitor simulation run time and subsequently kills any simulation that exceeded an unreasonable amount of time. In our initial batch of 1650 runs (30 design points times 55 reps per design point) 206, or 12.5% were terminated. Currently, we suspect the problem is an installation error.

As for the second hurdle, BRAWLER's user interface is archaic, consisting of hand editing text input files which in turn require extensive knowledge of the file formats. By today's standards, the user should never have to see a line of code. A Graphical User Interface (GUI) is not only necessary but should be required. Although, in today's budget conscious Air Force, the likelihood of this realization is nil. At the minimum, all users should have the DSA environment, or equivalent, and a basic set of scripts to automate some of the more mundane file editing chores. AWK scripts, such as the example in Appendix D, are powerful yet cumbersome tools requiring a good deal of platform and system knowledge.

Aside from BRAWLER issues, the most pressing area of additional research is to replicate the methodology of this thesis in a realistic modeling scenario. Use of the BBD employed and the hypothesized relationships between 4-ship entities and two 2-ship entities provide a means to truly investigate the viability of BRAWLER for quantifying reduced fighter pilot combat capability.

APPENDIX A - Design Matrix

The following list is composed of two parts—an unique design point number, or case number, and a factor level combination. The case numbers was used for tracking purposes, that is, for distinguishing one factor level combination, or design point from another. The output file names were appended with it's respective case number. The factor level combination represents the pilot's flight position and skill level setting. Below is the experimental design matrix, containing the 30 design points and their respective case number, studied in our research.

```
1011000     _BLUE1_ACE_ _BLUE2_ACE_ _BLUE3_PILOT_ _BLUE4_PILOT_
1101000     _BLUE1_ACE_ _BLUE2_PILOT_ _BLUE3_ACE_ _BLUE4_PILOT_
1110000     _BLUE1_ACE_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_ACE_
1112000     _BLUE1_ACE_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_ROOKIE_
1121000     _BLUE1_ACE_ _BLUE2_PILOT_ _BLUE3_ROOKIE_ _BLUE4_PILOT_
1211000     _BLUE1_ACE_ _BLUE2_ROOKIE_ _BLUE3_PILOT_ _BLUE4_PILOT_
2001000     _BLUE1_PILOT_ _BLUE2_ACE_ _BLUE3_ACE_ _BLUE4_PILOT_
2010000     _BLUE1_PILOT_ _BLUE2_ACE_ _BLUE3_PILOT_ _BLUE4_ACE_
2012000     _BLUE1_PILOT_ _BLUE2_ACE_ _BLUE3_PILOT_ _BLUE4_ROOKIE_
2021000     _BLUE1_PILOT_ _BLUE2_ACE_ _BLUE3_ROOKIE_ _BLUE4_PILOT_
2100000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_ACE_ _BLUE4_ACE_
2102000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_ACE_ _BLUE4_ROOKIE_
2120000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_ROOKIE_ _BLUE4_ACE_
2122000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_ROOKIE_ _BLUE4_ROOKIE_
2201000     _BLUE1_PILOT_ _BLUE2_ROOKIE_ _BLUE3_ACE_ _BLUE4_PILOT_
2210000     _BLUE1_PILOT_ _BLUE2_ROOKIE_ _BLUE3_PILOT_ _BLUE4_ACE_
2212000     _BLUE1_PILOT_ _BLUE2_ROOKIE_ _BLUE3_PILOT_ _BLUE4_ROOKIE_
2221000     _BLUE1_PILOT_ _BLUE2_ROOKIE_ _BLUE3_ROOKIE_ _BLUE4_PILOT_
3011000     _BLUE1_ROOKIE_ _BLUE2_ACE_ _BLUE3_PILOT_ _BLUE4_PILOT_
3101000     _BLUE1_ROOKIE_ _BLUE2_PILOT_ _BLUE3_ACE_ _BLUE4_PILOT_
3110000     _BLUE1_ROOKIE_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_ACE_
3112000     _BLUE1_ROOKIE_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_ROOKIE_
3121000     _BLUE1_ROOKIE_ _BLUE2_PILOT_ _BLUE3_ROOKIE_ _BLUE4_PILOT_
3211000     _BLUE1_ROOKIE_ _BLUE2_ROOKIE_ _BLUE3_PILOT_ _BLUE4_PILOT_
9001000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_PILOT_
9002000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_PILOT_
9003000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_PILOT_
9004000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_PILOT_
9005000     _BLUE1_PILOT_ _BLUE2_PILOT_ _BLUE3_PILOT_ _BLUE4_PILOT_
1000000     _BLUE1_ACE_ _BLUE2_ACE_ _BLUE3_ACE_ _BLUE4_ACE_
```

APPENDIX B - SCNRIO File

The BRAWLER scenario input file **SCNRIO**, specifies such general information as the length of the simulation, the types of aircraft involved, the types and numbers of stores loaded on the airframes, the status of the lprnts (switches which control the printing of diagnostic information), and initial disposition of flights [2, 3.2.1-1]. For a complete line by line description of a **SCNRIO** file, reference *The BRAWLER Air Combat Simulation User Manual*, Section 3.2.1 Scenario File. Below is a **SCNRIO** file representative of the files used in this research.

```
*******   4 V 4   *******
!Deleted last 4 Blue and 6 Red from 8V10 Community Version
!8V10 Community version Scenario RHMitchel: last modified MVK Tue Jun  1 1993
VERSION 1.0
600.  2.5   10. 12:00:00 1 31   ![4F] MAX SIM TIME,HIST INT,FINISH TIME,DAY
TIME,MONTH, DATE
0000000000, ,1, ,               ![I] RANDOM NUMBER SEED IF 00000000000 NEW PICK
F      1.0                      ![L,F] PERFECT_INFO SWITCH (T OR F),
FFFFFFFFFF                      ![10L] HRL MODE SWITCHES:  DO "ERC OP_MO
TFFTFTTFFFTFT  T FT FT TT       ![20L1,1L] OUE MODE SWITCHES, MOP SWITCH
!! 11 Apr 89 set ouemod switch 16 to true; prevents message delays
.5 50.
END                             !END CHECKPOINT DATA ![I,A,I]TIME
ON 130 201 256 33 176
END   DEFAULT_LPRNTS
0 1 2 3 4 5 6 7 8
ON 33 400
END   AC_DEP_LPRNT_SET
END   ALL_AC_DEP_LPRNTS         !each set has end label AC_DEP_LPRNT_SET
END   ALL_TIME_DEP_LPRNTS       !each set has end label TIME_DEP_LPRNT_SET
ALL
ALL
END   HIST_FOV_SPECS
00:00:00S      00:00:00E        ![2A] SCENARIO ORIGIN
"BLUE AB"     BLUE 00:00:00S   2:30:00W      ![4A] BASE NAME, SIDE,LAT/LON
"RED AB"      RED  00:00:00S   3:00:00E      ![4A] BASE NAME, SIDE,LAT/LON
"ALTBLUE AB"  BLUE 00:00:00S   3:30:00W      !SAME AS ABOVE; AN ALTERNATE
"ALTRED AB"   RED  00:00:00S   3:30:00E      !SAME AS ABOVE; AN ALTERNATE
END                             !END PRIMARY AND ALTERNATE BASE SPECIFICATIONS
0.25                            !GROUND RADAR REFLECTIVITY
70000.       71000.             ![2F] CLOUD LAYER BASE AND TOP
END                             !END ALL CLOUD LAYER SPECIFICATIONS
NOENV                           !IRST ENVIRONMENT NAME ("NOENV" IF NONE)
0.0                             !ECM NOISE LEVEL FRACTION (0.0 - 1.0)
"ACFT_BAC1"                     ![A] AIRCRAFT TYPE **BAC1**
FTR1         BLUE  0.0 0.0      ![2A] SUBTYPE NAME AND SIDE ("RED" OR "BLUE")
10.0         2.5                ![2F10] A/C INTRINSIC VALUE, COMBAT EFF
"MSLR"          MISL      4     ![2A,I] MISSILE NAME, NUMBER
"MSLI"          MISL      2     ![2A,I] MISSILE NAME, NUMBER
"GUN_0"         GUN       9     ![2A,I] GUN NAME, NUMBER
"FLARE"         EXP       8     ![2A,I] EXPENDABLE NAME, NUMBER
"CHAFF"         EXP      12     ![2A,I] EXPENDABLE NAME, NUMBER
"FCTL_1"        FCTL            ![2A] FIRE CONTROL DEVICE
"RDR1"          RDR             ![2A] RADAR NAME
"IRST_1"        IRST            ![2A] IRST DEVICE
"MWTEST"        MW              ![2A] MW DEVICE
```

```
"RWRTEST"       RWR             ![2A] RWR DEVICE

END                             !END OF AVIONICS STORES
13000.                          ![F] TOTAL EXTERNAL + INTERNAL FUEL AVAILABLE
END                             !END ALL SUBTYPES SPECIFIED FOR THIS AIRCRAFT
"ACFT_RAC1"                     ![2A] A/C TYPE SPECIFICATION  **RAC1**
FTR2      RED    0.0 0.0        ![2A] SUBTYPE NAME AND SIDE ("RED" OR "BLUE")
10.0       2.0                  ![2F] A/C INTRINSIC VALUE, COMBAT EFF
"MSLR"         MISL        2    ![2A,I] MISSILE NAME, NUMBER
"MSLR"         MISL        4    ![2A,I] MISSILE NAME, NUMBER
"MSLI"         MISL        2    ![2A,I] MISSILE NAME, NUMBER
"FCTL_2"       FCTL             ![2A] FIRE CONTROL DEVICE
"GUN_0"        GUN         9    ![2A,I] GUN NAME, NUMBER
"RDR2"         RDR              ![2A] RADAR NAME
"IRST_2"       IRST             ![2A] IRST DEVICE
"MWTEST"       MW               ![2A] MW DEVICE
"RWRTEST"      RWR              ![2A] RWR DEVICE
"TRX_R1"       IFF              ![2A] IFF DEVICE
"FLARE"        EXP        8     ![2A,I] EXPENDABLE NAME, NUMBER
"CHAFF"        EXP       12     ![2A,I] EXPENDABLE NAME, NUMBER
END                             !END OF STORES SPECS
10005.                          ![F10] TOTAL EXTERNAL + INTERNAL FUEL AVAIL
END                             !END ALL SUBTYPES SPECIFIED FOR THIS AIRCRAFT
"ACFT_RAC1"                     ![2A] A/C TYPE SPECIFICATION  **RAC1**
FTR3      RED   0.0 0.0         ![2A] SUBTYPE NAME AND SIDE ("RED" OR "BLUE")
10.0       2.0                  ![2F] A/C INTRINSIC VALUE, COMBAT EFF
"MSLR"         MISL        4    ![2A,I] MISSILE NAME, NUMBER
"MSLR"         MISL        2    ![2A,I] MISSILE NAME, NUMBER
"MSLI"         MISL        2    ![2A,I] MISSILE NAME, NUMBER
"FCTL_2"       FCTL             ![2A] FIRE CONTROL DEVICE
"GUN_0"        GUN         9    ![2A,I] GUN NAME, NUMBER
"RDR2"         RDR              ![2A] RADAR NAME
"IRST_2"       IRST             ![2A] IRST DEVICE
"MWTEST"       MW               ![2A] MW DEVICE
"RWRTEST"      RWR              ![2A] RWR DEVICE
"TRX_R1"       IFF              ![2A] IFF DEVICE
"FLARE"        EXP        8     ![2A,I] EXPENDABLE NAME, NUMBER
"CHAFF"        EXP       12     ![2A,I] EXPENDABLE NAME, NUMBER
END                             !END OF STORES SPECS
10005.                          ![F10] TOTAL EXTERNAL + INTERNAL FUEL AVAIL
END                             !END ALL SUBTYPES SPECIFIED FOR THIS AIRCRAFT
END                             !END ALL TYPES/SUBTYPES IN THIS SCENARIO
POD            OFF       RED    ![3A] POD ON SOJ, ON/OFF, SIDE OF SOJ
10.     0.0    1.        1.     ![4F] FIRST ORBIT POINT,X-Y(NM),ALTITUDE, SPEED
10.     -5.    1.        1.     ![4F] SUBSEQUENT ORBIT POINT, AT LEAST TWO
10.     0.0    1.        1.     ![4F] ADJACENT ORBIT POINTS MUST BE AT
10.     -5.    1.        1.     ![4F] MAXIMUM OF SIX LEGS MAY BE SPECIFIED
END                             !END FIRST SOJ POD/ORBIT SPECIFICATIONS
END                             !END ALL SOJ POD/ORBIT SPECIFICATIONS
20.  200.  15.  2.5  10.  2.5  5.0  10. 2.5  20.   !GCI CONSTANTS
END                             !END OF SFD/SAN DEVICE INFORMATION
1 2
3 4
END                             !END OF FLIGHTS ON THE SAME MISSION
"BLUE FTR FLT1"                 ![A] MOP FLIGHT NAME
AIRCRAFT                        ![A] ENTITY TYPE
2       1      2                ![3I] # A/C IN FLIGHT, # ELEM, INITIAL COMM CHAN
01 "ACFT_BAC1" FTR1 NOAWACS ACE ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
02 "ACFT_BAC1" FTR1 NOAWACS ACE ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
END                             !END TYPE/SUBTYPE FOR THIS FLIGHT
1
2
END                        !Inherent bias specification
01      "BLUE AB"  "ALTBLUE AB" ![I,2A] A/C NUMBER, HOME BASE,ALTERNATE
END                             !END OF MEMBER BASE SPECIFICATIONLTERNATEAS
12.5  -15.0  090.  50000.  1.4  0.0  ![6F] LEADER'S X-Y, HEADING, ALT, MACH,
01
```

```
02   0. 12000. 0.
END                                !END OF RELATIVE SPACING FOR THIS FLIGHT
!radar status: [IIAFFIFIA]
!ID,ANTEN,MODE,AZ_CTR,EL_CTR,NBAR,AZ_HW,INDEX,PRF_MODE
!                                |--SCAN--| |-TWS-|
01  01    SCAN 0.0     0.    2    45.      1   AUTO
02  01    SCAN 0.0    -6.    2    45.      1   AUTO
END                                !END OF RADAR SPECIFICATIONS
01    OFF                          ![I,A,4F] A/C ID, ON/OFF
02    OFF                          ![I,A,4F] A/C ID, ON/OFF
END                                !END OF SSJ SPECIFICATIONS FOR FLIGHT
01        00        00             ![I,2A] A/C ID, IFF DEVICE STATUS
02        00        00             ![I,2A] A/C ID, IFF DEVICE STATUS
END                                !END OF IFF DEVICE ON/OFF STATUS
01       ON         1              ![I,A,I] A/C ID, ON/OFF
02       ON         1              ![I,A,I] A/C ID, ON/OFF
END                                !END OF IRST STATUS
01       ON                        ![I,A,I] A/C ID, ON/OFF
02       ON                        ![I,A,I] A/C ID, ON/OFF
END                                !END OF MW STATUS
01 ON                              ![I,A]A/C AND STATE OF RWR
02 ON                              ![I,A]A/C AND STATE OF RWR
END                                !END OF RWR SPECS
01 ON                              ![I,A]A/C AND STATE OF MAW
02 ON                              ![I,A]A/C AND STATE OF MAW
END                                !END OF MAW SPECS
!ESM status: [IIAFFIFIA]
!ID,ANTEN, SOURCE,MODE,AZ_CTR,EL_CTR,AZ_WID,EL_WID
01   01 INTERNAL OFF               ![I,I,A,A]  A/C, FOV #, Source, Status
02   01 INTERNAL OFF               ![I,I,A,A]  A/C, FOV #, Source, Status
END                                !ESM Device status
1 OFF                              ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                       !END SAN CHANNEL STATUS
2 OFF                              ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                       !END ALL SAN CHANNEL SPECIFICATION
END SAN                            !ALL SAN SPECS FOR THIS FLIGHT
END                                !END OF FIRE CONTROL CONSTRAINTS
2.0      10.0       0.0            ![3F] AGRESSIVENESS, VFUEL, VTIME
0.99     0.99    1.50    0.99    1 ![4F,I] FIRE_DELAYS(IR,SEMI,ACTV,GUN), MAX TGTD
0.95     0.8     0.70    0.5   .55 ![5F] RPEAK  10.      10.     10.    10.0 10.0  !
NO_VIS_ID                          ![A] VISUAL ID NEEDED? ("NO_VIS_ID" OR "VIS_ID")
0.0 10.
ROUTE   200.     0.      45000.    ![I,F] MISSION TYPE,ROUTEPOINT
1.4     5.0      0.      000.      ![4F] LEG'S SPEED(MACH),VALUE,ARRIVAL TIME
END   ROUTE_SPECS
ENDBLOCK    MISSION_SUPP_DATA
ENDBLOCK    FLIGHT
"BLUE FTR FLT2"                    ![A] MOP FLIGHT NAME
AIRCRAFT                           ![A] ENTITY TYPE
2        1      2                  ![3I] # A/C IN FLIGHT, # ELEM, INITIAL COMM CHAN
01 "ACFT_BAC1" FTR1 NOAWACS ACE ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
02 "ACFT_BAC1" FTR1 NOAWACS ACE ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
END                                !END TYPE/SUBTYPE FOR THIS FLIGHT
1
2
END                                !Inherent bias specification
01      "BLUE AB"  "ALTBLUE AB" ![I,2A] A/C NUMBER, HOME BASE,ALTERNATE
END                                !END OF MEMBER BASE SPECIFICATIONLTERNATEAS
15.   4.0  090.  45000.  1.4  0.0   ![6F] LEADER'S X-Y, HEADING, ALT, MACH,
01
02 0. 12000. 0.
END                                !END OF RELATIVE SPACING FOR THIS FLIGHT
!radar status: [IIAFFIFIA]
!ID,ANTEN,MODE,AZ_CTR,EL_CTR,NBAR,AZ_HW,INDEX,PRF_MODE
!                                |--SCAN--| |-TWS-|
01  01    SCAN  0.0    -3.    2    45.    1     AUTO
02  01    SCAN  0.0    -9.    2    45.    1     AUTO
```

```
END                                     !END OF RADAR SPECIFICATIONS
01    OFF                               ![I,A,4F] A/C ID, ON/OFF
02    OFF                               ![I,A,4F] A/C ID, ON/OFF
END                                     !END OF SSJ SPECIFICATIONS FOR FLIGHT
01        00        00                  ![I,2A] A/C ID, IFF DEVICE STATUS
02        00        00                  ![I,2A] A/C ID, IFF DEVICE STATUS
END                                     !END OF IFF DEVICE ON/OFF STATUS
01        ON        1                   ![I,A,I] A/C ID, ON/OFF
02        ON        1                   ![I,A,I] A/C ID, ON/OFF
END                                     !END OF IRST STATUS
01        ON                            ![I,A,I] A/C ID, ON/OFF
02        ON                            ![I,A,I] A/C ID, ON/OFF
END                                     !END OF MW STATUS
01 ON                                   ![I,A]A/C AND STATE OF RWR
02 ON                                   ![I,A]A/C AND STATE OF RWR
END                                     !END OF RWR SPECS
01 ON                                   ![I,A]A/C AND STATE OF MAW
02 ON                                   ![I,A]A/C AND STATE OF MAW
END                                     !END OF MAW SPECS
!ESM status: [IIAFFIFIA]
!ID,ANTEN, SOURCE,MODE,AZ_CTR,EL_CTR,AZ_WID,EL_WID
01   01 INTERNAL OFF                    ![I,I,A,A]  A/C, FOV #, Source, Status
02   01 INTERNAL OFF                    ![I,I,A,A]  A/C, FOV #, Source, Status
END                                     !ESM Device status
1 OFF                                   ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                            !END SAN CHANNEL STATUS
2 OFF                                   ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                            !END ALL SAN CHANNEL SPECIFICATION
END SAN                                 !ALL SAN SPECS FOR THIS FLIGHT
END                                     !END OF FIRE CONTROL CONSTRAINTS
2.0      10.0       0.0                 ![3F] AGRESSIVENESS, VFUEL, VTIME
0.99     0.99   1.50   0.99    1 ![4F,I] FIRE_DELAYS(IR,SEMI,ACTV,GUN), MAX TGTD
0.80     0.8    0.70   0.5   .55 ![5F] RPEAK  10.     10.    10.   10.0 10.0  !
NO_VIS_ID                               ![A] VISUAL ID NEEDED? ("NO_VIS_ID" OR "VIS_ID")
0.0    10.0                             ![FF] Harddeck alt (ft), Value (nominally 10)
ROUTE   200.     0.0     40000.  ![I,F] MISSION TYPE,ROUTEPOINT
1.4     5.0    0.      000.             ![4F] LEG'S SPEED(MACH),VALUE,ARRIVAL TIME
END  ROUTE_SPECS
ENDBLOCK    MISSION_SUPP_DATA
ENDBLOCK    FLIGHT
"RED FTR FLT1"                          ![A] MOP FLIGHT NAME
AIRCRAFT                                ![A] ENTITY TYPE
2     1      3                          ![3I]NO. OF AC,NO. OF ELEM,INIT COMM CHANNEL
01    "ACFT_RAC1"   FTR2                ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
02    "ACFT_RAC1"   FTR3                ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
END                                     !END TYPE/SUBTYPE
1
2
END                                     !Inherent bias specification
01    "RED AB"      "ALTRED AB"  ![I,2A] A/C ID, HOME BASE, ALTERNATE BASE
END                                     !END OF BASES SPECIFICATIONS
53.0    -25.  270.  25000.  1.2   0.0 ![6F10]LEADER'S X-Y, HEADING, ALT, MACH,
01
02  -500. -09000. -1000.
END                                     !END OF RELATIVE SPACING FOR THIS FLIGHT
!radar status: [IIAFFIFIA]
!ID,ANTEN,MODE,AZ_CTR,EL_CTR,NBAR,AZ_HW,INDEX,PRF_MODE
!                                  |--SCAN--| |-TWS-|
01  01     OFF  0.0     -0.    2    45.    1       AUTO
02  01     OFF  0.0     -0.    2    45.    1       AUTO
END                                     !END OF RADAR SPECIFICATIONS
01   OFF                                ![I,A,4F] A/C ID, ON/OFF
02   OFF                                ![I,A,4F] A/C ID, ON/OFF
END                                     !END OF SSJ SPECIFICATIONS FOR THIS FLIGHT
01        00        00                  ![I,10A] A/C ID, IFF DEVICE STATUS
02        00        00                  ![I,10A] A/C ID, IFF DEVICE STATUS
END                                     !END OF IFF DEVICE ON/OFF STATUS FOR THIS FLIGHT
```

```
01        ON        1          ![I,A,I] A/C ID, ON/OFF
02        ON        1          ![I,A,I] A/C ID, ON/OFF
END                            !END OF IRST STATUS
01        ON                   ![I,A,I] A/C ID, ON/OFF
02        ON                   ![I,A,I] A/C ID, ON/OFF
END                            !END OF MW STATUS
01 ON                          ![I,A]A/C AND STATE OF RWR
02 ON                          ![I,A]A/C AND STATE OF RWR
END                            !END OF RWR SPECS
01 OFF                         ![I,A]A/C AND STATE OF MAW
02 OFF                         ![I,A]A/C AND STATE OF MAW
END                            !END OF MAW SPECS
!ESM status: [IIAFFIFIA]
!ID,ANTEN, SOURCE,MODE,AZ_CTR,EL_CTR,AZ_WID,EL_WID
01   01 INTERNAL OFF           ![I,I,A,A]  A/C, FOV #, Source, Status
02   01 INTERNAL OFF           ![I,I,A,A]  A/C, FOV #, Source, Status
END                            !ESM Device status
1 OFF                          ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                   !END SAN CHANNEL STATUS
2 OFF                          ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                   !END ALL SAN CHANNEL SPECIFICATION
END SAN                        !ALL SAN SPECS FOR THIS FLIGHT
END                            !END OF FIRE CONTROL CONSTRAINTS
2.0  10.0   0.0                ![3F] AGGRESSIVENESS, VFUEL, VTIME
0.99  0.99  1.50  0.99  2      ![4F,I] FIRE_DELAYS(IR,SEMI,ACTV,GUN), MAX TGTD
.75    .75   .75  .5    .55    ![5F] RPEAK  10.     10.     10.    10.0 10.0  !
NO_VIS_ID                      ![A] VISUAL ID NEEDED? ("NO_VIS_ID" OR "VIS_ID")
0.0    10.0                    ![FF] Harddeck alt (ft), Value (nominally 10)
ROUTE    50.0  0.   15000.     ![I,F] MISSION TYPE,ROUTEPOINT
1.4      50.0  0.     000.     ![4F] LEG'S SPEED(MACH),VALUE,ARRIVAL TIME
END  ROUTE_SPECS
ENDBLOCK     MISSION_SUPP_DATA
ENDBLOCK     FLIGHT
"RED FTR FLT1A"                ![A] MOP FLIGHT NAME
AIRCRAFT                       ![A] ENTITY TYPE
2     1      3                 ![3I]NO. OF AC,NO. OF ELEM,INIT COMM CHANNEL
01    "ACFT_RAC1"  FTR2        ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
02    "ACFT_RAC1"  FTR3        ![I,2A] A/C NUMBER, A/C TYPE, SUBTYPE
END                            !END TYPE/SUBTYPE
1
2
END                       !Inherent bias specification
01    "RED AB"     "ALTRED AB"  ![I,2A] A/C ID, HOME BASE, ALTERNATE BASE
END                            !END OF BASES SPECIFICATIONS
59.0   -15.  270.  25000.  1.2   0.0 ![6F10]LEADER'S X-Y, HEADING, ALT, MACH,
01
02  -500. -09000. -1000.
END                            !END OF RELATIVE SPACING FOR THIS FLIGHT
!radar status: [IIAFFIFIA]
!ID,ANTEN,MODE,AZ_CTR,EL_CTR,NBAR,AZ_HW,INDEX,PRF_MODE
!                         |--SCAN--| |-TWS-|
01  01    OFF  0.0    -0.    2    45.   1       AUTO
02  01    OFF  0.0    -0.    2    45.   1       AUTO
END                            !END OF RADAR SPECIFICATIONS
01   OFF                       ![I,A,4F] A/C ID, ON/OFF
02   OFF                       ![I,A,4F] A/C ID, ON/OFF
END                            !END OF SSJ SPECIFICATIONS FOR THIS FLIGHT
01        00        00         ![I,10A] A/C ID, IFF DEVICE STATUS
02        00        00         ![I,10A] A/C ID, IFF DEVICE STATUS
END                            !END OF IFF DEVICE ON/OFF STATUS FOR THIS FLIGHT
01        ON        1          ![I,A,I] A/C ID, ON/OFF
02        ON        1          ![I,A,I] A/C ID, ON/OFF
END                            !END OF IRST STATUS
01        ON                   ![I,A,I] A/C ID, ON/OFF
02        ON                   ![I,A,I] A/C ID, ON/OFF
END                            !END OF MW STATUS
01 ON                          ![I,A]A/C AND STATE OF RWR
```

```
02 ON                                !![I,A]A/C AND STATE OF RWR
END                                  !END OF RWR SPECS
01 OFF                               ![I,A]A/C AND STATE OF MAW
02 OFF                               ![I,A]A/C AND STATE OF MAW
END                                  !END OF MAW SPECS
!ESM status: [IIAFFIFIA]
!ID,ANTEN, SOURCE,MODE,AZ_CTR,EL_CTR,AZ_WID,EL_WID
01    01 INTERNAL OFF                ![I,I,A,A]  A/C, FOV #, Source, Status
02    01 INTERNAL OFF                ![I,I,A,A]  A/C, FOV #, Source, Status
END                                  !ESM Device status
1 OFF                                ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                         !END SAN CHANNEL STATUS
2 OFF                                ![I,A] A/C ID, ON/OFF SAN STATUS
END CHANNELS                         !END ALL SAN CHANNEL SPECIFICATION
END SAN                              !ALL SAN SPECS FOR THIS FLIGHT
END                                  !END OF FIRE CONTROL CONSTRAINTS
2.0  10.0   0.0                      ![3F] AGGRESSIVENESS, VFUEL, VTIME
0.99  0.99  1.50  0.99  2            ![4F,I] FIRE_DELAYS(IR,SEMI,ACTV,GUN), MAX TGTD
.75    .75   .750  .5    .55         ![5F] RPEAK 10.      10.     10.    10.0 10.0  !
NO_VIS_ID                            ![A] VISUAL ID NEEDED? ("NO_VIS_ID" OR "VIS_ID")
0.0    10.0                          ![FF] Harddeck alt (ft), Value (nominally 10)
ROUTE   50.0   0.   15000.           ![I,F] MISSION TYPE,ROUTEPOINT
1.4     50.0   0.     000.           ![4F] LEG'S SPEED(MACH),VALUE,ARRIVAL TIME
END  ROUTE_SPECS
ENDBLOCK    MISSION_SUPP_DATA
ENDBLOCK    FLIGHT
END    FLIGHT_SPECS
END    CARRIER_SPECS
BLUE OFF  RED OFF .2 .2  5. .2  .2 ![4A,5F] COMM JAMMING STUFF
! AUDIT
!! 30 Mar 95- dpc  Put ESM device status after MAW status
!!22 Mar 95 - dpc Added ESM Status Intialization lines for each A/C,FOV in a
flight
!!01 Jun 93 - mvk PRF control added to radar status line
!!07 Feb 92 - el TWS pattern bars/elevation replaced by pattern index
!!                antenna az/el centerline moved to STORED.
!!20 Dec 91 - mvk - Changes to match changes to mission section
!!21 Oct 91 - mvk - Changed to match changes labeled end cards
!!2 May 90 - rmk - Changed nominal lprnts line to all blanks, except for last
!! field.  The 1's in 161-175 are misleading, since these are defaulted
!! on
```

APPENDIX C - LPRNT Cross Reference Matrix

An often used diagnostic feature of BRAWLER are *lprnts*. During the debugging of programs, it is common industry practice to insert diagnostic print statements into the code. Prior to delivery these print statements are usually removed. However, in BRAWLER, all but the most arcane diagnostic prints were retained. To prevent unintentional execution of these print statements, their execution was made conditional on a logical flag (named *lprnt* flags after the data structure in which the flags are stored). An array of 240 different *lprnt* flags exist, with each flag controlling the output from a different routine or group of related routines. When a problem occurred during the debugging process, it could often be resolved by turning on certain *lprnts* and perusing the output for errors in the state of the program [2, 5.5-1]. Today, in addition to debugging, *lprnts* are commonly used to provide routine specific output for analysis purposes. *The BRAWLER Air Combat Simulation User Manual*, Section 5.5 Diagnostic Print Switches, provides a complete guide to initialization of *lprnt* flags. Below is a *lprnt* cross reference matrix of sample *lprnts* corresponding to routines that have to do primarily with the pilot's mental model. The first column contains the *lprnt* flag and the second column contains the corresponding routine or group of routines containing the flag. The third columns contains excerpts of the subroutine specific Fortran code to include a brief description of the subroutine's purpose, the code that tests for the condition of the *lprnt* flag, and the respective format statement of the resulting output.

LPRNT Cross Reference Matrix

LPRNT	SUBROUTINE	CODE EXCERPT
12	acfli	None
	cc2x3	None

	mindup	C#ABSTRACT UPDATES MENTAL MODEL OF CURRENTLY CONSCIOUS PILOT
		C#PURPOSE UPDATE MENTAL MODEL
		C#PARAMETER DESCRIPTIONS: none
		C#TECHNICAL DESCRIPTION
		C First process sensor data, after adding communicated sightings
		C to /sensed/. Process each aircraft first determining if new, and
		C then either adding or tracking. Update the significant change
		C list for all new or old aircraft with discrepancy in position.
		C Then process dc stream of new values (if communications-type c.e.)
		C and alter icparm.
		C Next, update missile envelope data for the proposed target if
		C the pilot posture decision has expressed interest in firing a
		C weapon.
		C Lastly, call major or minor update (as required), then call
		C preobs, premob, and prereq to send any a/c observational messages,
		C missile observational messages, and sighting update request
		C messages, respectively.
		
		if (lprnt) write(ioutp,1004)(indata(j),j=1,12),(a2(j),j=1,i)
		
		if (lprnt) write(ioutp,1002) icparm
		
		1002 format(' MINDUP...ICPARM',3x,3i1)
		1004 format(' MINDUP...INDATA DUMP FOR ICETYP =4'/
		     1 5x,'INDATA(1) THRU INDATA(12):',12i7/
		     2 5x,'A2:',(t10,i5,e13.5,i5,e13.5,i5,e13.5,i5,e13.5))

	Pl_mk_label	C#ABSTRACT Creates a list of labels from a list of real numbers
		C#PURPOSE Called when plmain is reading the PLIN file to create labels
		C that will be used to label the contours chen these plots are drawn
		C#TECHNICAL DESCRIPTION
		C Uses internal writes to create strings from the real numbers input.
		C Then strips off unnecessary spaces and zeros.
		
		if(lprnt)then
		            write(ioutp,*) 'pl_mk_labels...values(i_line)=',
		     1 values(i_line)
		            write(ioutp,*) 'pl_mk_labels...label before'//
		     1 'trimming=',labels(i_line)
		endif
		
		if(lprnt)write(ioutp,*) 'pl_mk_labels...trimming a zero'
		
		if(lprnt)then
		            write(ioutp,*) 'pl_mk_labels...label after'//
		     1 'trimming=',labels(i_line)
		endif

91	minud	C#ABSTRACT PERFORMS A PARTIAL SITUATION ASSESSMENT
		C#PURPOSE PERFORMS A PARTIAL UPDATE OF THE /MIND4/ SITUATIONAL
		C VARIABLES WHEN AT MORE FREQUENT INTERVALS THAN MAJOR UPDATES ARE
		C PERFORMED
		C#TECHNICAL DESCRIPTION
		C UPDATES SELF-ENGAGEMENT MEASURES FOR SELF VS. HOSTILES AND
		C HOSTILES VS. SELF ONLY. RECOMPUTES UTILITY-OF-ENGAGEMENTS USING
		C NEW SEM'S, BUT THE PREEXISTING EFFECTIVE HOSTILE VALUES. SEE
		C MAJUD.
		
		if(nbg.gt.0)then
		         if(lprnt) write(ioutp,6000) iacid
		
		if(lprnt)write(ioutp,6001) iacidt(iach),sem2(me,iach),
		     1 sem2(iach,me),ueng(iach)

		6000 format(' MINOR UPDATE FOR',i2,'...IACIDT,SEM2(F,H),SEM2(H,F),', 1 'UENG:') 6001 format(5x,i2,3f8.3)

116	mindup	C#ABSTRACT UPDATES MENTAL MODEL OF CURRENTLY CONSCIOUS PILOT
		C#PURPOSE UPDATE MENTAL MODEL
		C#PARAMETER DESCRIPTIONS: none
		C#TECHNICAL DESCRIPTION
		C First process sensor data, after adding communicated sightings
		C to /sensed/. Process each aircraft first determining if new, and
		C then either adding or tracking. Update the significant change
		C list for all new or old aircraft with discrepancy in position.
		C Then process dc stream of new values (if communications-type c.e.)
		C and alter icparm.
		C Next, update missile envelope data for the proposed target if
		C the pilot posture decision has expressed interest in firing a
		C weapon.
		C Lastly, call major or minor update (as required), then call
		C preobs, premob, and prereq to send any a/c observational messages,
		C missile observational messages, and sighting update request
		C messages, respectively.
		
		if (lprnt2.and.nspotd.gt.0)then
		call asstgt(iactgt,aidtgt,virtl)
		headng = atan2(vp(1,me),-vp(2,me))
		if (headng.lt.0.) headng = headng+twopi
		write(ioutp,1006) iacid,ppmjid,aidtgt
		do 150 iac=2,nspotd
		call vsub(xp(1,iac),xp(1,me),dx)
		azim = atan2(dx(1),-dx(2))
		if (azim.lt.0.) azim = azim+twopi
		bearng = azim-headng
		if (bearng.gt.pi) bearng = bearng-twopi
		if (bearng.le.-pi) bearng = bearng+twopi
		elev = arcsin(-dx(3)/rngnow(iac,me))
		aspect = (pi-obang(iac,me))/rad
		call lockid(iacid,iacidt(iac),locked)
		write(ioutp,1005) iacidt(iac),rngnow(iac,me)*ftnmi,
		1 obang(me,iac)/rad,aspect,azim/rad,elev/rad,bearng/rad,
		2 locked
		150 continue
		endif
		
		1005 format(10x,'A/C =',i2,' RNG =',f5.1,'NM. OBA =',f5.0,
		1 ' ASPECT =',f5.0,' AZIM =',f5.0,' REL ELEV, BRNG =(',f5.0,',',
		2 f6.0,'). LOCKED=',i2)
		1006 format(5x,'MINDUP...IACID=',I2,'...OTHER STATUS: PPMJID =',i2,
		1 ' ASSTGT =',i2)

	perfrm	C#ABSTRACT COMPUTES A/C PERF VARIABLES IN /MYPFRM/
		C#PURPOSE COMPUTES A/C PERF VARIABLES IN /MYPFRM/
		C#TECHNICAL DESCRIPTION
		C THE COMPUTATION OF ALL VARIABLES EXCEPT GMXSU AND CORNRV ARE
		C ROUTINE. SINCE GMXSU IS INTENDED NOT AS THE TRUE MAX SUSTAINED
		C GEE CAPABILITY, BUT RATHER AS THE MAX GEE'S THAT THE PILOT WILL
		C USE IN ANY SITUATION EXCEPT EXTREME EMERGENCY, IT MUST BE
		C SENSITIVE TO A NUMBER OF NON-AERODYNAMIC FACTORS. FACTORS INCLUDE
		C INTEREST IN FIRING A WEAPON AND RANGE TO NEAREST HOSTILE OR HOSTILE
		C MISSILE.
		C LOOP 10 COMPUTES DRAG-VERSUS-LIFT AND AOA-VERSUS-LIFT TABLES,
		C GIVEN CURRENT SPEED, ALTITUDE.
		
		if(lprnt) then
		write(ioutp,1000) iacid,-xp(3,me)/1000.,
		1 xmag(vp(1,me))/vsme,gcap(1),vsme,cornrv/vsme
		write(ioutp,1100) (thrstl(i),i=-1,3)
		write(ioutp,1200) gmxsu,gmxsut
		write(ioutp,1201) amxin,aoamx,dragvl
		write(ioutp,1202) 'aoavl',aoavl
		write(ioutp,1202) 'drgaoa',drgaoa
		endif

		1000 format(' perfrm...A/C',I3,';',F5.1,' kft,',F5.2,' Mach,',F5.1, 1 ' Max G: Vs=',F7.1,' fps, Vc=',F5.2,' Mach') 1100 format(' PERFRM...thrstl = ',5(f12.3,1x)) 1200 format(' PERFRM',t10,'GMXSU=',f7.2,t30,'GMXSUT=',f7.2) 1201 format(' perfrm...amxin=',f5.1,' aoamx=',f6.3/ 1 5x,'dragvl =',(t20,5f10.0)) 1202 format(5x,a,' =',(t20,1p,5e11.3))
190	cc2x3	C#ABSTRACT ADDS A NEWLY DETECTED AIRCRAFT TO THE MENTAL MODEL C#PURPOSE ADDS A NEWLY DETECTED AIRCRAFT TO THE MENTAL MODEL C#TECHNICAL DESCRIPTION C Increment NSPOTD and NINMM. Determine its relationship (friendly, C unknown, or hostile?). Set several of the various mind variables C from the observed values. Use one of ECMTKI (ecm obs), MSVOBS/ C TRKACI (imperfect information), IRSTKI (irst), or M3PERF (perfect C information) to initialize state vector in mind for the target. C complete miscellaneous mind variable initialization; exit. C Several variables are only set if ispotd .le. mxacmm because they C are only used by code which only considers the mxacmm most important C a/c. If an a/c later gets swapped into one of these lower numbered C slots, the swapping code will reset these variables. if (lprnt3) write(ioutp,6003) ninmm,iacid,nspotd 6003 format(1x,'CC2X3...there are now ',i3, 1 ' aircraft in the mental model of aircraft ',i3,/, 2 ' (',i3,' are under detailed consideration)')

	mm_est_init	C#ABSTRACT Initializes mental model track establishment value and status
		C#PURPOSE Whenever a new track is created in the mental model (cc2x3),
		C this routine is called to set the initial establishment value
		C and status using the observation source and mode.
		C#TECHNICAL DESCRIPTION
		C The observation in /sensed/ contains two variables, jnform and
		C jnform_mode, which give the observation source and the mode the
		C source was in. /mindc/ contains an array of establishment values
		C which is indexed by the source and mode. This routine sets the
		C track establishment value in /mind3/ to the value in /mindc/. It
		C then tests this against the establishment threshold in /mindc/ to
		C see if the track is to be marked as established or not.
		
		if (lprnt) then
		text = char_mm_est(mm_est_sta(ispotd))
		write(ioutp,6000) iacidt(ispotd),
		1 text(1:rspace(text)),mm_est_val(ispotd)
		endif
		
		6000 format(' MM_EST_INIT...Track on a/c #',I2,' is initially ',A,
		1 ', estab value = ',F8.3)

	mm_est_upd	C#ABSTRACT Updates mental model track establishment value and status
		C#PURPOSE Whenever an existing track is updated with a new observation
		C (cc2x2), this routine is called to update its establishment
		C value with the value associated with that type of obs.
		C Track establishment status may also be changed as a result.
		C' Note that the establishment value is first propagated to the
		C observation time before the additional value is added.
		
		if (lprnt) then
		text = char_mm_est(mm_est_sta(ispotd))
		write(ioutp,6000) iacidt(ispotd),
		1 text(1:rspace(text)),mm_est_val(ispotd)
		endif
		
		6000 format(' MM_EST_UPD...Track on a/c #',I2,' is now ',A,
		1 ', estab value = ',F8.3)

	mm_est_prj	C#ABSTRACT Projects mental model track establishment value and status C#PURPOSE This routine is called from cc2x4 to project the track C establishment value and status to the current time.

		<pre>if (lprnt) then
		        text = char_mm_est(mm_est_sta(ispotd))
		        write(ioutp,6000) iacidt(ispotd),
		     1 text(1:rspace(text)),mm_est_val(ispotd)
		endif
		
		6000 format(' MM_EST_UPD...Track on a/c #',I2,' is now ',A,
		     1 ', estab value = ',F8.3)</pre>

	mmordr	<pre>C#ABSTRACT Reorganizes a pilot's mental model, if necessary
		C#PURPOSE Executive for swapping aircraft in a pilot's mental model.
		C Puts the highest valued aircraft in the group of aircraft that will
		C be considered in detail.
		C#TECHNICAL DESCRIPTION
		C First checks to see if the pilot is in a limited awareness (high
		C stress) situation. Next, sets the size of the detailed consideration
		C group, which may depend on whether or not pilot is in a limited
		C awareness situation.
		C Next, determines the values of the aircraft in the mental model with a call
		C to SWAPVL. Then the lower limit on the value of aircraft that will be
		C part of the detailed decision group is obtained. Finally, a loop over
		C all aircraft in the detailed decision group is performed. If the
		C value of any aircraft in the detailed decision group is lower than the
		C minimum value, that aircraft is swapped with an aircraft that is
		C currently outside of the detailed decision group. By definition there
		C must be an aircraft with a high value outside of the current detailed
		C decision group if an aircraft currently in the detailed decision group
		C has a low value.
		
		20 if (lprnt) write(ioutp,6500) 'After considering saved high
		     1 consideration list, lim_aware =',lim_aware
		
		40 if (lprnt) write(ioutp,6500) 'After considering all observed
		     1 hostiles, lim_aware =',lim_aware
		         endif
		
		if (lprnt) write(ioutp,6600) mac,mxacmm
		
		if (n_mm_est .le. mxacmm) then
		         if(lprnt) write(ioutp,6001)
		
		if (lprnt) write(ioutp,7000) minval
		
		if (lprnt) then
		         if (nspotd .gt. 1) then
		            write(ioutp,8500)
		            do 1500 kk = 1,ninmm
		               if (kk .le. nspotd) then
		                  write(ioutp,8601)kk,iacidt(kk),
		     1 char_mm_est(mm_est_sta(kk))
		               else
		                  write(ioutp,8600)kk,iacidt(kk),
		     1 char_mm_est(mm_est_sta(kk))
		               endif
		1500 continue
		            write(ioutp,8000) nspotd
		         else
		            write(ioutp,8100)
		         endif
		endif</pre>

	`6500 format(1x,a,L5)`
	`6600 format(1x,' MMORDR...max ac allowed in mental model:',i5/`
	`     1 t10,'# ac allowed in high detail =',i5)`
	`6001 format(1x,' MMORDR...number of a/c that are established ',`
	`     1 'in mental model is .le. mxacmm')`
	`7000 format(1x,' minimum value for detailed consideration = ',F7.3)`
	`8000 format(1x,' (*The first ',I2,`
	`     1 ' aircraft are in the detailed consideration group)')`
	`8100 format(1x,' Pilot has only himself in his detailed ',`
	`     1 'consideration group')`
	`8500 format(1x,' MMORDR...Mental model slot #',T35,`
	`     1 'Tail #',T53,'Status')`
	`8600 format(1X,T18,I2,T38,I2,T49,A)`
	`8601 format(1X,T18,I2,T38,I2,T49,A,'*')`

mremac	`C#ABSTRACT DELETES AN AIRCRAFT FROM THE CURRENT MENTAL MODEL`
	`C#PURPOSE  DELETES AN AIRCRAFT FROM THE CURRENT MENTAL MODEL`
	`C#TECHNICAL DESCRIPTION`
	`C     Considers bvr target information if radar was tracking the`
	`C  aircraft being removed.  Adjusts aggressiveness values depending`
	`C  on side of dead aircraft.  Makes self element leader if the`
	`C  element leader is the aircraft being deleted.  Calls dsitng to`
	`C  note the aircraft's removal for the history file.  Removal uses`
	`C  routine polst0 repetitively.`
	
	`if (lprnt) write(ioutp,6000) iacidt(jspotd),jspotd,iacid,time`
	
	`if (lprnt) write(ioutp,6001)`
	
	`if (lprnt) then`
	`            if (jspotd .le. nspotd)  then`
	`               write(ioutp,6001)`
	`            else`
	`               write(ioutp,6002)`
	`            endif`
	`endif`
	
	`6000 format(1x,'MREMAC...removing aircraft ',i3,`
	`     1 '(mental model # ',i3,') from mental model of ',i3,' at ',f6.1)`
	`6001 format(1x,'MREMAC...aircraft is in detailed decision group')`
	`6002 format(1x,'MREMAC...aircraft is not in detailed decision group')`

swapmm	`C#ABSTRACT Swaps aircraft in a pilot's mental model`
	`C#PURPOSE  This routine should be used when the location of an aircraft`
	`C in the mental model is important.`
	`C#TECHNICAL DESCRIPTION`
	`C  The only variables which are swapped are those which are in the`
	`C include files /MIND3/ and /MIND3A/.  It is assumed that the other`
	`C common blocks will be rebuilt AFTER the mental model swapping has`
	`C occurred, either by subroutine mreset or majud.`
	
	`if (lprnt) then`
	`         write(ioutp,6000) index1,index2,iacid`
	`endif`
	
	`6000 format(1x,'SWAPMM...swapping aircraft in slots ',i3,' and ',i3,`
	`     1 ' of mental model of aircraft ',i3)`

swapvl	C#ABSTRACT Returns an array of values used in mental model priority decisions. C#PURPOSE Computes a value for each aircraft in the current pilot's C mental model. These values are used to determine which C aircraft will be represented in full detail in the mental C model. C#TECHNICAL DESCRIPTION C Routine loops through all of the slots in the mental model and, for C occupied slots, accumulates a total value based on a sum of individual C values which are themselves based on the following considerations: C Time of arrival - Determined by a call to valtoa, this is actually a C sum of values associated with the estimated time of C other aircraft's arrival at long range, then medium C range, then close range, assuming constant velocity for C both aircraft. C Chaseability - Time of arrival if the current aircraft were C pointing directly at the other aircraft and moving at C current speed or bvrmch, whichever is greatest. C This factor is further adjusted to account for the C amount of time required to turn toward the other C aircraft. C Hysteresis - Aircraft which had the highest values last time C around receive additional weight. Note that C nspotd_old is used instead of nspotd, since nspotd C may have changed, and we want to add the hysteresis C value to all a/c that were in the detailed C consideration group last time.. C Targets on missile BVR list C Currently selected target C Target assigned by flight leader C Aircraft whose identity is unknown C Aircraft in my flight C Aircraft known to be hostile C Aircraft biased by production rules C Hostiles or unknowns close to GCI vectors C Bombers I am assigned to escort C Once these values are computed, the scores for all non-established C tracks are scaled so that they all score less than the lowest scoring C established track. C Finally, scores of the established tracks are adjusted to keep the C pilot's formation leader (or one other friendly) and the highest scoring C hostile in the detailed consideration group if they are established.

```
if (lprnt) write(ioutp,2000) iacid,time,ninmm

if (lprnt) write(ioutp,3000) iac,iacidx(iac)

if (lprnt) write(ioutp,4000) ' TIME OF ARRIVAL', vtoa

if (lprnt) write(ioutp,4000) '    CHASEABILITY', vtoac*angfct

if (lprnt) write(ioutp,4000) '      HYSTERESIS', addfac

if (lprnt) write(ioutp,4000) '      BVR TARGET', addfac

if (lprnt) write(ioutp,4000) ' SELECTED TARGET', addfac

if (lprnt) write(ioutp,4000) 'FLT LEADER ORDER', addfac

if (lprnt) write(ioutp,4000) '     UNKNOWN A/C', unkval

if (lprnt) write(ioutp,4000) '     FLIGHT MATE', addfac

if (lprnt) write(ioutp,4000) '   KNOWN HOSTILE', addfac

if (lprnt) write(ioutp,4000) 'PROD RULE BIAS',

if (lprnt) write(ioutp,4000) '   GCI VECTORING',addfac

if (lprnt) write(ioutp,4000) '   BOMBER ESCORT',addfac

if (lprnt) write(ioutp,5000) vv

if (lprnt) write(ioutp,5500) iacidt(iac),swpvls(iac)

if (lprnt) then
         write(ioutp,6000)
      endif

if (lprnt .and. iac_frn.ne.0) then
         write(ioutp,6100) iac_frn,swpvls(iac_frn)
      endif

if (lprnt) write(ioutp,6200) iac_hos,swpvls(iac_hos)

1000  format(' SWAPVL...A/C #',I3,' HAS NO TAIL NUMBER FOR MM INDEX ',
     1 I3,', NINMM = ',I3)
2000  format(' SWAPVL...COMPUTING SWAPPING VALUES FOR A/C #',I3,
     1 ' AT TIME = ',F8.3,' SECONDS'/
     2 '         MENTAL MODEL CONTAINS ',I3,' A/C, INCLUDING SELF')
3000  format('       COMPUTING VALUE FOR MM-SLOT #',I3,',  A/C #',I3)
4000  format('       ',A25,' FACTOR, VALUE = ',F5.3)
5000  format('       TOTAL SWAPPING VALUE = ',F7.3/)
5500  format('       A/C #',I2,
     1 ' NOT ESTABLISHED, REDUCING SWAPPING VALUE TO ',F7.3/)
6000  format(' SWAPVL...value of largest friendly and hostile')
6100  format(1x t10,'frndly mm slot =',i5,' with swapping value =',f7.3)
6200  format(1x,t10,'host mm slot =',i5,' with swapping value =',f7.3)
```

APPENDIX D - AWK Post-Processing Script

This appendix contains two AWK programing scripts used to post-process the BRAWLER simulation output. This scripts were provided by AFSAA. The first one **BVRTOOL** generates a report by calling several other scripts. The only pertinent script, **ER.AWK**, which was used to calculate the MOEs has been included for completeness.

BVRTOOL

```
#!/bin/csh
set tools=/usr/apps/brawler/TOOLS
echo "AFSAA/SAG"
echo "BVRTOOL"
date
echo   ""
echo   " INPUT FILES: $1"
setenv extension `nawk -f $tools/getFile.awk $1`
#grep $extension many/README*
grep $extension README*
echo   ""
echo   "er.awk"
awk -f $tools/er.awk $1
echo   ""
echo   "howdied.awk"
awk -f $tools/howdied.awk $1
echo   ""
echo   "msldb.awk"
nawk -f $tools/msldb.awk $1 > database.$extension
echo  "ALL SHOTS"
echo   "mslext.awk"
nawk -f $tools/mslext.awk database.$extension
echo   ""
echo   "rng_aspect"
nawk -f $tools/rng_aspect.awk database.$extension
echo   "mslavg.awk"
nawk -f $tools/mslavg.awk database.$extension
echo   "mslfail.awk"
nawk -f $tools/mslfail.awk database.$extension
echo   ""
echo ""
echo "First Shots Only"
nawk -f $tools/first_shot.awk  database.$extension > database.$$
echo   "mslext.awk"
nawk -f $tools/mslext.awk database.$$
echo   ""
echo   "rng_aspect"
nawk -f $tools/rng_aspect.awk database.$$
echo   "mslavg.awk"
nawk -f $tools/mslavg.awk database.$$
mv database.$extension reports
echo "Completed Processing"
rm database.$$
grep ALIVE $1
```

ER.AWK

```
BEGIN
  {
  cases = 0 ;
  btot = 0 ;
  rtot = 0 ;
  balive = 0 ;
  ralive = 0 ;
  bdeadsq = 0;
  rdeadsq = 0;
  expect_blue_loss = 0 ;
  expect_blue_kill = 0
  }
#
  /ALIVE/ && /TOTAL/
  {
  cases++
  btot+=$2       ; rtot+=$6
  balive+=$12    ; ralive+=$17
  bdeadsq+= ($2-$12)*($2-$12);
  rdeadsq+= ($6-$17)*($6-$17);
  }
#
END
  {
  bdead = btot - balive     ; rdead = rtot - ralive
  print cases " runs BLUE: " btot " airplanes - " balive " alive = "
              bdead " died"
  print cases " runs  RED: " rtot " airplanes - " ralive " alive = "
              rdead " died"
  b_loss = bdead/btot * 100
  expect_blue_loss = bdead / cases
  blue_loss_variance =
   (bdeadsq - (cases*expect_blue_loss*expect_blue_loss))/(cases - 1);
  printf("     BLUE LOSS PER ENGAGEMENT = %5.2f",expect_blue_loss);
  printf(" OR %6.2f PERCENT",b_loss);
  printf(" LOSS STDERR %6.2f\n",sqrt(blue_loss_variance/cases));
  b_leth = rdead/rtot * 100
  expect_blue_kill = rdead / cases
  red_loss_variance =
   (rdeadsq - (cases*expect_blue_kill*expect_blue_kill))/(cases - 1);
  printf("     BLUE LETH PER ENGAGEMENT = %5.2f",expect_blue_kill);
  printf(" OR %6.2f PERCENT",b_leth);
  printf(" LETH STDERR %6.2f\n",sqrt(red_loss_variance/cases));
  if (bdead > 0) {
                  kratio = rdead/bdead;
                  print "     EXCHANGE RATIO = " kratio
                 }
  }
```

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13. ABSTRACT *(Maximum 200 words)*

BRAWLER is a high resolution air-to-air combat simulation model used for engagement-level analyses of few-on-few air combat. It uses a value driven decision logic to help simulate pilot behavior. In order to account for varied pilot skill levels, BRAWLER has defined three skill levels; Rookie, Pilot, and Ace. A Rookie can track up to three aircraft in its mental model, the Pilot, up to five aircraft, while an Ace has no limit. Further, each skill level varies the amount of time before a known aircraft, which has not been recently observed, is purged from the pilot's mental model (i.e., memory time). Past analyses using BRAWLER have exclusively used Ace pilots. This thesis focuses on the effects due to pilot skill level in air-to-air combat by using different combinations of Rookie, Pilot, and Ace skill levels in the BRAWLER air-to-air engagement model.

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